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Znanstveno područje: humanističke znanosti
Znanstveno polje: filologija
Znanstvena grana: anglistika

Mentor: izv. prof. dr. sc. Goran Schmidt
Osijek, 2024.

Prilog: izjava o akademskoj čestitosti i o suglasnosti za javno objavljivanje

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U Osijeku, 14. LIPNJA 2024.

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Abstract

This master's thesis covers the translation theory regarding the scientific and technical translation and examines its practices on a real-life example of academic writing. This thesis discusses translation theory/ies regarding translation in general, but it increases its focus later on scientific and technical translation with an aim to contextualise the means of translating scientific and technical texts. In regards to scientific and technical translation, it is important to look at the style and discourse, purpose, and target readers of this type of translation. In the practical part of the following chapters, we analyse the source text's structure and language, which will be of benefit for the next chapter where the translation problems are analysed and multiple solutions are proposed. The aim of the practical part of this master's thesis is to test some of the theories that translation studies proposes to aid scientific and technical translation.

Keywords: translation theory, scientific and technical translation, source text, target text, translation problems, translation solutions

Sažetak

Ovaj diplomski rad bavi se teorijom znanstvenog i tehničkog prevođenja te ispituje praksu teorije na stvarnom primjeru znanstvenog rada. Ovaj rad raspravlja o znanosti o prevođenju općenito, ali kasnije skreće jaču pažnju znanstvenom i tehničkom prevođenju kako bi se kontekstualiziralo načine prevođenja znanstvenih i tehničkih tekstova. U kontekstu znanstvenog i tehničkog prevođenja važno je razmotriti stil i jezik, cilj i potencijalnu publiku ove grane prevođenja. Praktični dio ovog rada analizira strukturu i jezik izvornog teksta, što je od velike koristi za dio rada koji analizira prijevodne probleme i predlaže različita prijevodna rješenja. Cilj ovog dijela rada je testirati teorije znanosti o prevođenju koje nude pomoć pri znanstvenom i tehničkom prevođenju.

Ključne riječi: znanost o prevođenju, znanstveno i tehničko prevođenje, izvorni tekst, ciljni tekst, prijevodni problemi, prijevodna rješenja

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1. Introduction

The current globalised world longs for uninterrupted communication and exchange of information from all fields of human expertise and all world languages. With this in mind, it is obvious that there would be a larger pool of translation industry experts attempting to maintain said communication and exchange across nations of the world.

Not only is translation a common communicational placeholder of the world, but it also has a long-recorded history:

> "The first traces of translation date from 3000 BC, during the Egyptian Old Kingdom, in the area of the First Cataract, Elephantine [...]. It became a significant factor in the West in 300 BC, when the Romans took over wholesale many elements of Greek culture, including the whole religious apparatus. In the twelfth century, the West came into contact with Islam in Moorish Spain. [...] When the Moorish supremacy collapsed in Spain, the Toledo school of translators translated Arabic versions of Greek scientific and philosophical classics. Luther's Bible translation in 1522 laid the foundations of modern German and King James's Bible (1611) had a seminal influence on English language and literature." (Newmark 2001: 3)

One can simply see how translation proposes itself easily as the only solution to bridge linguistic and cultural differences between multiple nations in question. However, translation has faced several changes in societal attitudes towards its status as an industry, and the most significant change in attitudes towards translation came in the twentieth century, commonly rephrased as the "age of translation" (cf. Newmark 2001: 3). The biggest cause of this was, as mentioned in the beginning, the overall globalisation seen in examples of establishments of new international bodies and institutions, as well as multinational companies, which gave this industry "enhanced political importance" (Newmark 2001: 3).

The main problem with translation as an industry was lack of understanding of the way this industry functions in terms of the processes a source text or produced speech undergoes to be translated into a target language of the target audience, as the interest for the translation processes came mostly on individual level of professionals in this field (cf. Ivir 1995: 517). It would, in fact, only take the last century's increasing needs for translation to actually stir some interest in the way the translation processes work, resulting in a new, young academic discipline which would study translation processes. Other historical instances of attempt to explain translation theory came from increased need for the same industry in the past (cf. Munday 2008: 7). Language is the key communication medium of the human kind, but the multitude of different national languages causes communication barrier, which makes both language and translation communication acts in same respect (cf. Ivir 1978: 9), but as language was considered the primary communication act, translation was deemed of secondary importance until the 20th century and all of the previously described developments in the industry (cf. Munday 2008: 8).

Another subject matter significant to the theme of this discussion is the distinction between literary and technical translation as two recognized branches of translation that are differentiated through their linguistic structure and approaches to translation. Sometimes the said differences between literary and technical translation resulted in positive bias towards literary translation, regarding technical translation as secondary and easier work which is only to focus on content, whereas literary translation has to take care of form (cf. Newmark 2001: 5).

The difference in approach to translation is already visible in literary translation in the attitude that one must be tuned to the flow of the text and be able to intuitively generate a proper translation of a literary text (cf. Munday 2008: 149). Even the contemporary attitude towards literary translation expresses the opinion that the literary translation is to be dynamic rather than formal (cf. Nida 1964: 130). The biggest challenge that literary translation faces would most likely be to convey the relation between the source language and culture and display it in matters of target language and culture as appropriately as possible, hence literary translation wouldn't "communicate the foreign author's intentions, but [try to] create a relationship to the linguistic and literary conventions of the translating culture that matches the relationship between the foreign text and its own culture" (Venuti 2004: 338).

Scientific and technical translation differs from literary translation in its stern approach to terminology and linguistic structure, which in past led to the most commonplace myth given to this field of translation: "In the past some translators have maintained that technical translation is solely a matter of correctly transferring technical content and that style is not the province of the technical translator" (Herman 1993: 3). However, it would be ridiculous to not consider the primary characteristics, i.e. goals, of both technical writing and translation of "clarity, concision and correctness" (Herman 1993: 11) as certain stylistic characteristics. Even if these characteristics are to be ignored, Sue Ellen Wright (1993: 69 – 86) proves style to have significant importance in technical (and scientific) translation on situational, macrocontextual, microcontextual, and terminological unit level, which are to be discussed in following theoretical chapters of this thesis.

The theme of this master's thesis is the scientific and technical translation through the lens of translating an engineering academic paper. This thesis is to cover the background of translation theory regarding its history and status as an academic discipline, and more precisely, scientific and technical translation as a special branch of this discipline. This thesis analyses the relevant translation theory in regards to general translation and more precisely the scientific and technical translation and contextualises the translation theory and reviews it through the text analysis and translation process of a text from the field of mechanical engineering. The aim of this thesis is to improve the understanding of the mechanics of scientific and technical translation as it appears proactively on a real translation example and to further clarify all of the steps included in the translation process to produce a high-quality translation of a mechanical engineering academic paper with great content clarity.

This master's thesis is divided into the theoretical and the practical part. The theoretical part in chapter (2) covers the translation theories regarding translation in general, further increasing focus on translation theory regarding scientific and technical translation through its sections. The most prominent names describing the overall translation theory mentioned in this paper include Newmark (2001), Venuti and his collection of influential work in regards to translation studies (2004), and Ivir (1978 and 1995) as the most prominent name in Croatian translation studies, while the most contribution for describing scientific and technical translation goes to Ralph Krüger and authors writing for Scientific and Technical Translation published by American Translators Association. Chapter (3) highlights the source text, its author, theme, and most common keywords. The practical part in chapter (4) covers two units: (1) text analysis and (2) translation commentary. In text analysis in section (1), we analyse the text structure and the linguistic features characteristic for this text with an aim to create a good basis for its translation, while section (2) discusses terminology issues faced during translation process. In the section (3) with translation commentary, we look at some of the most problematic parts of the text and discuss solutions to ensure that the new target text has great content clarity and optimal terminological consistency. The conclusion to this thesis follows in chapter (5). Chapter (6) gives an overview of sources used to aid the research for this master's thesis.

2. Theoretical background

2.1. About general translation studies and translation theory. Background, name, definition

As mentioned in the beginning, the 20th century’s increased demand for translators also increased the need the scholars expressed for a special discipline that would be dedicated to the translation process. Newmark also notices how the increasing number of text editing teams especially including translators and revisors results in longing for establishing a distinct translation theory (cf. Newmark 2001: 4 – 5).

This discipline meant to study the translation process is thus relatively new among academics and is still emerging in the body of research regarding the translation process and translation theory. In fact, it was only in the fifties that it was attempted to establish the said discipline as translation science and to start opening new study programmes across the universities (cf. Ivir 1995: 517). Ivir (1995: 518 – 21) recognizes four problems with the attempts to establish this discipline as a science: (1) where on the discipline spectrum translation science finds itself, (2) if the name translation science (with the stress on word *science*) should be accepted or changed into more appropriate term, (3) if any of the proposed terms can be justified in regards to scientific prestige and the expectations this field can fulfil, and (4) the fact that the English term "translation studies" does not have a Croatian equivalent suitable to the nomenclature of scientific disciplines and fields. The first problem shows to find most common solution in the view that translation studies are inherently interlingual and interdisciplinary, as they involve "any language combinations, various branches of linguistics, comparative literature, communication studies, philosophy and a range of types of cultural studies including postcolonialism and postmodernism as well as sociology and historiography" (Munday 2008: 1). Considering the name of the discipline, translation science, in Croatian "*znanost o prevođenju*", is deemed a more careful attempt to name this new discipline in Croatian academic system, which seems suitable with the meaning of doing scientific research into the discipline, whereas in English, the term *science* would prove to not be adequate with its meaning of established laws of nature and theory (cf. Ivir 1995: 519). Furthermore, the justification of the field researching translation shows to be more empirical than the most, and it is even proposed that the translation theory be divided into "pure" translation theory and "applied" translation theory (cf. Toury 1995: 10 as shown in Munday 2008: 10). Relating to the point of inadequacy of term "translation science", "translation studies" is deemed to be the most appropriate way to name this discipline in English, but then it is not at all equivalent to the Croatian nomenclature, nor can Croatian have an equivalent to the widely accepted English name for this discipline (cf. Ivir 1995: 519). This then leaves this translation discipline to already have widely different names in respect to the belonging national academic systems. However, even in the English nomenclature one can notice differences in naming this field, with the most common synonym being "translation theory" (cf. Newmark 2001).

With this beginning point of the establishment of the new scientific discipline and its emerging status in the academic scene (cf. Venuti 2004: 3), it was important to now define this new discipline and what its aim is. Munday (2008: 1) proposes a simple definition of translation studies as "the academic discipline related to the study of the theory and phenomena of translation". In relation to the previous point that this field is fairly empirical, it is stressed that "translation theory is an independent linguistic discipline, deriving from observations and providing the basis for practice" (Newmark 2001: 9). Holmes (1972: 176) also agrees and claims this field to be "an empirical discipline". However, it has been argued in the beginning that there's a "lack of any general consensus as to the scope and structure of the discipline. What constitutes the field of translation studies?" (Holmes 1988: 175) It is further agreed that "the increasingly interdisciplinary nature of translation studies has multiplied theories of translation" (Venuti 2004: 4), which complicates the aims to define the aforementioned scope of translation studies. A noticeable pattern in all of the history's translation theories is, however, the interconnection between the concepts of notorious equivalence and function (cf. Venuti 2004: 5). Conclusively, regarding the empirical and study nature of this discipline, "translation theory is an independent linguistic discipline, deriving from observations and providing the basis for practice" (Newmark 2001: 9).

With the history and multifaceted definition of translation studies and translation theory in mind, there's still a question of what is assumed about the translation process and all of the side processes that aid the translation process. This paper is not to go into details of translation studies, but is instead to cover some of the most basic notions of what translation process requires of a translator and/or its source text. Translator is to develop understanding and high level of critique in order to be able to translate a source text into a target text for selected audience: "A translator requires a knowledge of literary and non-literary textual criticism, since he has to assess the quality of a text before he decides how to interpret and then translate it" (Newmark 2001: 5). By translating, humanity attempts "coming to terms with the foreignness of languages" (Benjamin 1923: 19). However, the common problem that resurfaces in respect to the existence of multiple languages is the so-called "translatability" of a text (Benjamin 1923: 16). Translatability in this sense is to be seen as proximity of significance of messaging between the original and the translation since the translation does not bring the message in the same respect as the original (cf. Benjamin 1923: 16), which is also the domain in which the translator would likely have to employ any knowledge and criticism required for a source text analysis.

Even as the translatability has been assessed, the next important task is to see how much textual equivalence can be kept in translation of the text. The biggest issue with how equivalence is viewed is the preset limitations on the ideas of equivalence, which will be further demonstrated in this paragraph. The first factor that can influence the textual equivalence is the quality of the source text: “If the writing is poor, it is normally [translator’s] duty to improve it, whether it is technical or a routine, commercialized best-seller” (Newmark 2001: 6). The second factor would be the evaluation of how free a translation can be, as freedom in contrast to fidelity “have traditionally been regarded as conflicting tendencies” (Benjamin 1923: 21). In this respect, the textual equivalence becomes a more complicated aspect of the text, especially because equivalence holds a lot of value as the first association with translation – translation is deemed a replacement of one expression with another expression of an equal meaning in a different language (provided that the translation in question would be of interlingual type) (cf. Ivir 1987: 13). On the contrary, some establish that there is “no full equivalence between code-units [...] [with] the example of *cheese* in English, which is not identical to the Russian *syr* [...]” (Munday 2008: 37). First (and successful) attempt at freeing the scope of equivalence from limiting ideas from the past stems from Nida’s work while translating The Bible: he set the categories of so-called (1) “formal equivalence” and (2) “dynamic equivalence” with the main difference being that the latter fulfils the functional equivalence necessary to adapt the text to the target language and culture, whereas the formal equivalence is set to focus both on the textual content and its form (cf. Munday 2008: 42).

Newmark (2001) placed a lot of importance on the level of omission of meaning. Each translator has to decide for themselves how much they will keep or omit in their translation:

> “Translation is a craft consisting in the attempt to replace a written message and/or statement in one language by the same message and/or statement in another language. Each exercise involves some kind of loss of meaning, due to a number of factors. It provokes a continuous tension, a dialectic, an argument based on the claims of each language. The basic loss is on a continuum between overtranslation (increased detail) and undertranslation (increased generalization).” (Newmark 2001: 7)

Newmark finds some of the causes for the loss of meaning: (1) culture and the linguistic landscape, (2) basic linguistic differences between two languages, (3) idiolect usage, and (4) differences in values and priorities when reading a piece of text between the translator and the original author (cf. 2001: 7 – 8).

With everything mentioned in mind, it is easy to see the common consensus that translator is to at least produce a translation with content equivalence of the same effect on the reader of the target public as the original's on the audience of the source language (cf. Newmark 2001: 10).

2.2. Scientific and technical translation

Scientific and technical translation (later in text: STT) within the field of technical communication has been given a crucial role in international exchange of scientific and technical information. This is the most obvious in the consensus that, as the companies are spreading across the world, "technical communicators can no longer afford to take an ethnocentric approach to creating documents" (Flint et al. 1999: 238), i.e. the language of technical texts produced in company's source culture is to be written in the most neutral register possible. This shift in paradigm about writing texts for purposes of technical communication is a testimony of the importance of technical communication for the entire world and, as formerly mentioned in previous chapters, for information exchange.

In regards to STT, it would be beneficial to cover the discourse around it before an actual definition of STT to see the overall status of this type of translation compared to other types of translation. The first part of the discourse stems from a positive bias towards the artistry of literary translation and negative bias towards the directness of technical translation. The negative attitude towards STT can firstly be seen in the fact that there's a scarcity of research articles discussing this type of translation in comparison to literary translation – which is seen as a consequence of the attitude that STT is easier due to the universality that science globally imposes, as well as the lack of creative freedom that would usually be imposed in literary work and literary translation (cf. Krüger 2015: 42). Many other authors further agree with this notion, as is the case with the following statement: "In the past some translators have maintained that technical translation is solely a matter of correctly transferring technical content and that style is not the province of the technical translator" (Wright and Wright 1993: 3). The matter of style and whether or not it is needed in STT is the most common reason for the negative attitude towards this type of translation, and the section 2.2.1. below will serve as proof that this attitude towards STT is false. Oftentimes it is also noted that "Despite the high societal relevance of this field of translation, [...] a brief survey of current translation studies shows that STT is far from an obvious choice of topic since, as an object of investigation, it is often considered to lack the multidimensionality and general appeal of other types of translation" (Krüger 2015: 24). How all of these factors result in a lack of prestige status of STT compared to literary translation is best summarized by Newmark:

> "All kinds of false distinctions have been made between literary and technical translation. Both Savory (1957) and Reiss (1971) have written that the technical translator is concerned with content, the literary translator with form. Other writers have stated that a technical translation must be literal, a literary translation must be free [...]. A traditional English snobbery puts literary translation on a pedestal and regards other translation as hackwork, or less important, or easier. [...] A translator must respect good writing scrupulously by accounting for its language, structures and content, whether the piece is scientific or poetic, philosophical or fictional. If the writing is poor, it is normally his duty to improve it, whether it is technical or a routine, commercialized best-seller." (Newmark 2001: 5 – 6)

This quote perfectly transfers this thesis to the part of discourse which is marked by more positive attitudes towards the importance of STT in the same respect that has been mentioned in this thesis a couple of times. While literary works and literary translation are pillars of humanity's culture, STT, technical dictionaries, technical texts, scientific publications, etc. are all pillars of human knowledge accumulated throughout the millennia. Translating scientific and technical texts, as well as creating specialised bilingual technical dictionaries, holds significant place in this and serves as communication medium among various national scientific and technical societies: "Would the world's scientific knowledge have been as effectively enriched or the ideas of these great scientists been as rapidly brought to the attention of the scientific world had they been left untranslated?" (Fischbach 1993: 92) Alongside the importance, there are also some myths that have been empirically debunked in terms of previously mentioned style and level of complexity of STT:

> "The translation of a scientific treatise is both more difficult and more readily accomplished than the translation of a novel or essay; more difficult because it requires in addition to a mastery of two languages, a reasonably thorough knowledge of the subject under discussion; more readily accomplished because elegance of expression must give place to accuracy of translation." (Scientific American 1900: 354)

Krüger also expresses that with his experience of working in the field of STT came the conclusion that STT and technical texts are highly complex and that, in all its complexity, STT deserves its own studies and research (cf. 2015: 24). One can also notice the shift in roles of scientific and technical translators, as according to Joël Larrue, technical translator is no longer merely a "'bilingual clerk' condemned to work in isolation, without resources or recognition, he is now a linguist, a technician, and an expert" (1982: 17).

When both positive and negative attitudes towards STT are taken into consideration, it is important to properly define STT. Most researchers usually place an emphasis of a type of source text as the starting point to define STT, such as Mark Herman. Herman (1993: 11) comments on division of types of translation according to text: "Burton Raffel divides translation into three basic categories according to the source text: nonliterary prose (including technical material), literary prose, and poetry." What is also respected with all three types of translation is the necessity to hold knowledge and ability to produce the message equal to the source document (cf. Herman 1993: 11 – 12). Translation of nonliterary prose, under which falls the STT as well, is hence to follow the exact meaning of the source text as clearly as possible, whereas "Purposeful ambiguities, ungrammatical constructions and sound combinations which call attention to themselves are the province of literary translation" (Herman 1993: 13). After this distinction, it is also important to define technical text as an important factor of STT: "In general, we define a technical text as one that deals with the design, manufacture, construction, use, maintenance, and repair of an object created by man, ranging from simple, everyday objects to complex systems" (Larrue 1982: 15). However, it should be pointed out that Larrue also mentioned that the best way to know that the text is not purely technical is to analyse whether or the technical content of the text plays a primary or a secondary role (cf. 1982: 16). The section 2.2.3. also covers some characteristics of technical texts described in his work "Technical Translation in Canada: A Giant Effort" present in *Technical Communication* according to topic and, most importantly, target audience. Seeing technical translation through the text definition may seem a little bit limiting, but the main root of the problem is lack of research of STT. As previously mentioned, studies dedicated to STT are limited in quantity, hence there is no real established study covering the topic of STT: "The designation scientific and technical translation studies is not intended to imply that we are dealing here with an established research paradigm such as descriptive translation studies (Toury 1995) or corpus-based translation studies (Baker 1996) – quite the contrary is true" (Krüger 2015: 23).

What may also raise some questions is the name of this type of translation and studies covering it: scientific and technical translation. Some may ask whether they are purposefully put together or they have their differences and are supposed to be individual entities in translation studies. The greatest (and perhaps the only) contributor to this discussion is Ralph Krüger (2015) with his work in *The Interface between Scientific and Technical Translation Studies and Cognitive Linguistics*. Krüger (2015: 34) found that there is concern regarding whether STT should really remain STT as in "scientific *and* technical translation or rather [...] scientific *vs.* technical translation". It should be noted that the terms "science" and "technology" (in Croatian also *znanost* and *tehnologija*) are frequently found together as a binominal phrase in news and academic work (cf. Olohan 2009: 246 in Krüger 2015: 33). However, what can be noticed during the research for this master thesis is that this type of translation is more commonly referred to as just technical translation, and there are multiple examples of this occurrence. Joël Larrue (1982: 15 – 17) exclusively uses the denominations "*technical* text", "*technical* translation", and more importantly, "*technical* translator". Sue Ellen and Leland Wright Jr., although naming their publication “scientific and technical translation”, introduce their readers to “*technical* translation”, while also introducing the denomination “*technical* terminology" (1993: 1). One work influential to guidelines of creating *technical* texts is named *Technical Translation* (Flint et al. 1999) and is used to aid *technical* communicators write translatable *technical* texts. Meanwhile, among the body of work used for research for this master thesis, only one work talks about *scientific* translation, while also acknowledging the necessity for *technical* dictionaries (cf. Scientific American 1900: 354). In regards to such discourse about scientific and technical translation where there is an obvious emphasis on the *technical* part, it is obvious that scientific and technical translation are perhaps not opposed to one another, instead it seems that *scientific* translation is aided by a more independent branch of *technical* translation.

In order to keep the discussion going, it would be interesting to see in detail the style of STT, the purpose of such texts, and the target audience of scientific and technical translation. The biggest contributor to style and content analysis of scientific and technical translation is Mark Herman for *Scientific and Technical Translation* (1993), while Reiß and Vermeer (2013) will serve as a reminder of *skopos* theory in the context of STT and its intended purpose. Target audience deserves its own analysis as there would likely be an obvious distinction depending on the level of an individual’s prior knowledge about any subject of scientific and technical texts, which will be further discussed in section 2.2.3. with some interesting remarks on modern-day problem of digitalisation of technical communication job as experienced by Rice-Bailey (2014).

2.2.1. Stylistic makeup, content, and language of scientific and technical texts and translation

As seen in the previous chapter, scientific and technical translation does not get much recognition nor credit in translation studies. Translators and scholars found this type of translation to lack the complexity, creativity, and most importantly style: “In the past some translators have maintained that technical translation is solely a matter of correctly transferring technical content and that style is not the province of the technical translator” (Wright and Wright 1993: 3). It must be clarified now that contemporary translation studies understand how these beliefs have been false, which will be further proven in following paragraphs.

Before the beginning of discussion about style of translation, readers should be reminded of the previously mentioned fact that “A translation of technical prose, though non-literal, should convey the exact meaning of the original text as directly as possible. Purposeful ambiguities, ungrammatical constructions and sound combinations which call attention to themselves are the province of literary translation” (Herman 1993: 13). For the sake of the flow of this discussion, it would be beneficial to continue with Mark Herman and his proposition of what a style of scientific and technical translation looks like. Herman claims that clarity, concision, and correctness are "the principal stylistic goals of technical writing [...] [and] simultaneously those of technical translation" (1993: 11). He deems clarity to be an important factor in forming lexically and syntactically clear sentence structures, especially since languages differ on a syntactic level (cf. Herman 1993: 14). Clarity influences translations in a way that they stop being literal compared to the original text: sometimes one changes syntax of the translation, sometimes adds new information, and sometimes omits unnecessary parts (cf. Herman 1993: 14 – 15). Although Herman refers comparatively to German (and to some extent French) and English, the same goes for all languages. Later Herman moves on to concision to define it as the hardest work on style of a technical translation that does not even pay off, as it is not materialised the same way as is the word count (cf. 1993: 17). However, concision helps with the organisation of the produced translation to make more sense to the target readers (cf. Herman 1993 ibid.). Along with clarity and concision, correctness is crucial in two different senses: accurate depiction of original text in a translation and accurate technical text in the target language without mistakes in the original text (cf. Herman 1993: 18). Herman goes on to conclude and explain that the demonstration of work needed for technical translation shows how STT isn't merely a job of "writing down the dictionary equivalents of words" (1993: 19). It seems though that clarity, concision, and correctness are self-understood factors to STT, but what about some of the genuine stylistic hallmarks of this type of translation and how to define style in the context of various types of translation on a self-proposed spectrum between literary translation and STT? Sue Ellen Wright steps up with the statement that style is to be seen as a broader term:

> "At the outset, it is important to note that by 'style' I am using the word in the broad sense that is understood by most American translators. In this regard, style refers to a wide scala of considerations, ranging from the overall structural form of the entire text to lexical choice at sentence fragment level. [...] the full gamut of these factors plays a role in selecting appropriate translation solutions." (1993: 69)

This seems like an ideal starting point as different authors prioritise different textual levels to analyse or give rules for in terms of writing and/or translating. Wright fills in to define style of STT on different stylistic levels, as enlisted: 1) situational, 2) "macrocontextual", 3) "microcontextual", and 4) terminological level (cf. 1993: 72). Situation level is represented by the external, or the environment influencing the source text, the "macrocontext" is the text in its entirety, the "microcontext" represents the locality of terminology that is a pillar of a scientific and technical text, and terminological units are mostly isolated individual units (cf. Wright 1993: 72).

One expected hallmark of STT, which was already discussed in the previous chapter, is the approach to translating the technical text, but before the overview of all of the approaches to STT summed up, it would be beneficial to summarise types of translation according to Vinay and Darbelnet. The two main groups of approaches to translation include direct and oblique translation (cf. Vinay and Darbelnet 1995: 31). They argue that some texts allow "to transpose the source language message element by element" either because of "parallel categories" or "parallel concepts" (Vinay and Darbelnet 1995 ibid.). This may be the reason why many experienced technical translators also noticed that the direct translation actually is quite common in STT (cf. Byrne 2012: 119). However, even Jody Byrne agrees that this is not a whole picture: "Even the process of adjusting elements of a source text so that they conform to TL [target language] grammar can be a complex process" (2012 ibid.). The reason why it is still unfair to simplify and reduce STT to literal transition from source to target language word by word is because STT and its style is heavily influenced by the primary goal of conveying the information from the source text as clearly as possible (cf. Krüger 2015: 26). Not only that, but sometimes even the original writer of technical texts is a well-versed writer:

> "But sometimes it happens that a scientific writer is not only a man of thought, but also a man of considerable literary ability, who clothes his thought in phrases and sentences artistically formed and grouped. The translation of the writings of such a man, ceases to be merely an intellectual task; it becomes an undertaking in which the feeling and good taste of the translator are called into requisition to reproduce as faithfully as possible the style as well as the intellectual traits of original." (Scientific American 1900: 354)

However, certain attempts to describe the style of STT can potentially cause further misunderstanding of how STT isn't as easy as is believed. Although these attempts are useful guidelines to other technical translators trying to master their craft, these attempts also push the stereotype about STT further that this type of translation is simplistic, and an example of this can be seen in the fact that some believe that the texts can be "more readable by keeping sentences as short as possible and by using simple sentence structures and words" (Byrne 2012: 145). But it is an important reminder that translators need to think about various factors that influence the translation. Sometimes it is complicated to do STT of a source text with long strings of sentences (notorious in German language) into more simplistic discourse with simple sentences, because "facility with the source language is important, but facility with the target language is crucial" (Herman 1993: 19). Creating a sequence of simple sentences in a target text from long strings of complex sentences in a source text can also be as complicated as detangling a heavily metaphoric literary text.

It is also worth mentioning that one of the factors that influence STT and technical texts itself is the so-called "information dynamics" (Gerzymisch-Arbogast 1993: 26). Sequence of given and new information is considered to influence the text discourse influenced by the author-reader relationship (cf. Gerzymisch-Arbogast 1993: 21). The next sections will thus give a great look to how both information (and its goal in context of technical communication) and target audience shape STT and translator's choice of words, terminology, and textual order from bigger chunks of information such as chapters to the smallest details on a clausal level.

2.2.2. The purpose of scientific and technical texts and translation in context of global technical communication

While it has been previously repeated numerous times that the technical communication and STT as a part of it serve for greater exchange of information among scientific and technical societies across all nations, it is time to analyse how this plays a role in the purpose of STT, and therefore technical communication as well. This importance is firstly seen in fact that there are online courses about writing technical texts that are easily readable and "translation-friendly" (Flint et al. 1999: 238).

Before an actual look into the purpose of STT and technical texts, reader should be reminded of *skopos* and how it is crucial in translation studies. This term was first coined by Hans J. Vermeer, and he explains its role and nature in his collaborative work with Katharina Reiß of a title in English *Towards a General Theory of Translational Action*. The word *skopos* stems from Greek and means "purpose" or "aim" (cf. Vermeer and Reiß 2013: 86). Vermeer reflects firstly how one does not simply state that a certain text is technical or literary, but the decision to translate one as such depends on the said *skopos* (cf. Reiß and Vermeer 2013: 27). While introducing the readers into the theory behind *skopos*, Vermeer comments how motivations and goals precede current events and how they alter course of actions, rather than the current events being merely a constant state:

> "An action aims to achieve a goal and thus to alter the current state of affairs. The motivation for such an action is that the intended goal is estimated to be of greater importance than the current state of affairs. Sometimes, an action is preceded by a chain of motivations: if somebody acts under compulsion, this aim may be estimated to be of lesser value than the current state of affairs but compliance may be less damaging than resistance. An action is always preceded by (conscious or unconscious) expectations about a future situation in comparison to how the current situation has been assessed." (Reiß and Vermeer 2013: 85)

This is later on crucial for describing actions in translation. Vermeer talks about the theory of action describing how the actions of a person stem from their assessment of a situation (cf. Reiß and Vermeer 2013 ibid.). While comparing this theory to translation, he states that "a theory of translational action begins with a situation that always includes a preceding action, i.e. the source text" (Reiß and Vermeer 2013 ibid.). The most important claim in this introduction is that "a translational action is governed by its purpose" (Reiß and Vermeer 2013 ibid.), meaning that the original text's purpose determines how the said original text will be translated. This is the main sentence that leads to the definition of *skopos* rule in translation deemed the highest rule: "any action is determined by its purpose, i.e. it is a function of its purpose or *skopos*" (Reiß and Vermeer 2013: 90).

There are some attitudes and ways in which *skopos* is reflected in STT, including some special(ised) translation theories. Firstly, many agree that translation "is always a purpose-driven activity which is linked to specific motivations" (Krüger 2015: 291). Furthermore, it seems that finding the purpose in scientific and technical texts is not as simple as to credit it solely for technical communication: the most important notion is adequacy, and it can be exemplified in adaptations which are heavily dependent on target audience ranging from experts to general public trying to understand a scientific and/or technical text (cf. Reiß and Vermeer 2013: 126 – 7). How this is manifested based on the target audience is a part of section 2.2.3 below. A way in which *skopos* manifests itself is through defining what communicative function technical texts and STT have:

> [...] Snell-Hornby unsurprisingly claims that the prototypical function of scientific and technical translation is the informative one. [...] What I want to point out here is that the informative function (in its different manifestations) is so closely linked to scientific and technical discourse that the variance of this skopos (to use the central term of German functionalism, see Reiß/Vermeer 21991) seems to be a very peripheral phenomenon in scientific and technical translation, where functional invariance seems to be the norm. (Krüger 2015: 50 – 1)

This shows that it is crucial to maintain communicative function from source text into the target text and thus maintain this functional invariance (cf. Nord 2007: 36). This can be an issue since language and expression are influenced by culture, and thus translation needs to be done well enough that the "given information" is seen as relatable to target readers, which in turn means that the illustrative/informational purposes have been fulfilled (cf. Gerzymisch-Arbogast 1993: 39). Styling a translation is in this sense influenced by purpose:

> "In contrast to indicative translations generated strictly for in house research purposes, translations produced for the purpose of communicating with individuals outside corporate structures must conform to the same criteria that are imposed on original source texts in the target language intended for the same audience." (Wright 1993: 70)

In regards to everything stated about communicative functions of source text and target text, text analysis based on this typology serves to discern the purposes of source text and target text (cf. Gommlich 1993: 179).

A special term used in context of STT, technical texts, and technical communication definitely worth mentioning in the context of purpose of STT is so-called “language for special purposes”, LSP, which is crucial “for capturing the different degrees of technicality of scientific and technical texts” (Krüger 2015: 26). One of the features of LSP is the so-called “scientific and technical register” (cf. Gerzymisch-Arbogast 1993: 21). In this regard, LSP can be seen as text typology intended for STT (cf. Nord 2007: 130).

The final question is what is the real purpose of technical texts and STT. While the purpose of the source text and the target text are crucial factors at play, a factor that, again, seems to be heavily stressed, is the “recipient’s knowledgebase for understanding the SL [source language] and TL [target language] text” (Gommlich 1993: 180). Gommlich still warns that this factor of understanding also includes the fact that there may be different views and understandings on text purposes (cf. 1993 ibid.). So firstly, source text and target text would need to fulfil “informational purposes” (Krüger 2015: 422). This can be also described as “a fluid transfer of ideas: reading information in one language and writing it down in another” (Larrue 1982: 15). This should not surprise as it is also claimed that “other forms of translational action may involve actions like a consultant giving information” (Nord 2007: 11), and this is something Vermeer would describe using the term “offer of information” (Reiß and Vermeer 2013: 33 – 84). Joël Larrue gives an interesting observation later in his work describing characteristics of technical text: one of the characteristics enlisted is that they all have their aim to either explain an action of a reader regarding the object in terms of reparation or maintenance and/or to inform a reader about the products and its use (cf. 1982: 16).

This in turn ends in an intact *status quo* for the purpose of the STT and technical texts. While the overall self-evident purpose of STT and technical texts is technical communication and exchange of information from a source language into a target language, the real purpose lies in the target audience meant to read these technical texts and translations, i.e. the real purpose of STT is to share information with the target audience adapting to their previous knowledge.

2.2.3. *Target audience of the scientific and technical texts and translations - impact of target audience on final translation product*

As a starting point, it may be useful to see what the relation between the technical communicators and/or translators and their target audience looks like. It is useful to look at what can be said about analysing target audiences in *Using Target Audience Analysis to Aid Strategic Level Decisionmaking* by Steve Tatham (2015), because it focuses on strategic decision-making and communicating decisions to their varied target audience – which seems to be useful for technical communication as well. It is generally believed that the information is communicated and "communication is two way – and what is received by the audience (which may not be the intended one) is often at significant variance to what is intended" (Tatham 2015: 10).

While Tatham's work focuses on military strategies in the USA, it gives one more good insight on the way target audiences react to information: "Audiences do not sit passively and receive messages; instead they contextualize them according to a host of external factors" (2015: 11). This imposes the question of who can be potential target audiences of scientific and technical texts and translation. While the answer may vary, one part of analysing the target audience involves getting to know "the background knowledge of the reader" (Krüger 2015: 46). With this in mind, it would still be good to see how proximity of technical communicators and/or translators to their target readers and audiences impacts translation. Tammy Rice-Bailey discussed in her article "Remote Technical Communicators" how, after she worked on-site for her former company, she already had difficulties with her access to audiences in the new company where she worked as a remote technical communicator (cf. 2014: 96). She reports that this area of work as technical communicator has not been researched before and they faced unique challenges while addressing target audience, but this has started to change since increase in digital workplaces for technical communicators (cf. Rice-Bailey 2014 ibid.). In her study, some reported negative impact of lack of contact with the target audience, while some explained that most of their projects did not even require said contact (cf. Rice-Bailey 2014: 99). This impact is also seen in their lack of socialisation with their audience and teams (cf. Rice-Bailey 2014: 101), and while it may seem irrelevant, this may cause problems trying to relate to the people one is writing a piece of text or translating for. Understanding that the way technical texts are written and/or translated depends on the prior knowledge may get some help with distinction between two largest distinctions of target readers:

> "Narrative texts usually refer to situations, actional contexts and actions that are more or less well-known by the text recipients, the new elements being primarily the relations [...]. Expository texts, on the other

> hand, usually do not only refer to new relations between individual events but to new events altogether, [...]. Also, Jahr (2009:82) points out that scientific and technical knowledge is quite strongly organised in a vertical hierarchy that often encompasses more and much deeper reaching levels than in other disciplines. In order to understand a highly specialised scientific/technical text, readers normally have to acquire first the basic knowledge at the top of such a hierarchy [...] and then work their way downwards to increasingly more specific levels of knowledge." (Krüger 2015: 46)

In this case one can see how not only does the translator have to hold a higher level of knowledge on the subject, but also the reader would have to be well-read and/or well-versed in the subject of STT.

However, the overall rule for translators may be that "the translator has to assist his reader" (Newmark 2001: 28). In this respect, the translator has to make the text as accessible as possible to the reader content-wise (cf. Newmark 2001 ibid.). This in turn debunks the view that target text production is to merely look at the way source text is produced, since the target audience as one of the external factors is one of the most crucial influences on the translation process and translation product (cf. Krüger 2015: 56). The way this is supposed to work is to have translator organise information for target readers in an alternate sequence of "given" and "new" data, but these pieces of data are to be seen as relative, depending on what translator defines as "given" or "new" to the target audience (cf. Gerzymisch-Arbogast 1993: 23 – 24). Larrue also mentions among his characteristics of technical texts that, as they primarily deal with concrete object and its physical reality and are intended by well-versed writers for readers already informed at least to some level about a subject, their objective is still to explain the way an object works and/or the way a person is to handle the object (cf. 1982: 16). The way the text communicates and/or explains certain subjects can therefore depend on the communication direction: "Another difference between these three modes of communication is the fact that, moving from expert-to-layperson to expert-to-expert communication, the group of intended readers usually becomes increasingly smaller." (Krüger 2015: 70)

Target audiences are an important aspect to the *skopos* of translation as well: "A skopos cannot be set unless the target audience can be assessed. If the target audience is not known, it is impossible to decide whether or not a particular function makes sense for them" (Reiß and Vermeer 2013: 91). Wright describes her experience revising a translation of one manual intended for an American audience when her customer was not satisfied with her revision (cf. 1993: 76 – 7). The root of the issue ended up being divided into two factors: 1) the intended purpose of the manual (a marketing text) and 2) cultural differences between the German audience of the source text (since its original language was German) and the American audience of the target text (cf. Wright 1993: 77). The cultural differences have shown the content asymmetry between the source text and the target text, e.g. instead of company history in German original, American audiences would expect a presentation of the company and CEO's current status (cf. Wright 1993 ibid.).

The influence of the target audience of any scientific and technical texts and/or translations on the aim, process, and product of the text and/or translation shows itself to be impactful in a couple of ways. The first way how this is shown is in how texts are shaped depending on the audience's prior knowledge of the subject, the second way in how the text is formed and organised to convey the information the best way possible, and the third way in what the text aims to inform the reader about.

3. Methods and sample text for translation solution analysis

With the full consideration of the theoretic background behind STT and the way it is fabricated, it is beneficial to look at how all of the aforementioned hallmarks of scientific and technical texts and translation are represented in an example of a scientific text selected for the analysis purposes for this thesis.

The scientific text in question stems from mechanical engineering. The authors of this article are Peter Kurath and Jason Howard Jones and the title of it is "Multiaxial Thermomechanical Deformation Utilizing a Non-Unified Plasticity Model". This article is available on JSTOR and was published in *SAE Transactions* in 2001.

This article explores uniaxial and multiaxial deformation in context of previously established deformation models, as the authors stress that modelling "inelastic deformation is of practical interest in many design applications, especially with the current emphasis on lighter weight structures and components operating at higher temperatures" (Kurath and Jones 2001: 1). The main issue with thermomechanical deformation is the change in material properties dependent mostly on temperature, which is known to cause linear and volume expansion of mass. However, there are limits to thermomechanical loading which a material can take, which causes deformation reactions of materials ranging from time-independent strains to the time-dependent strains, especially including creep. The reason the research is done via non-unified model, as given in the title, is because "distinct or independent mechanisms govern time dependent and independent plastic deformations" (Kurath and Jones 2001: 1).

While this analysis seems to merely summarise the idea of this scientific article, it is notable for this topic for a couple of reasons: 1) this is a purely scientific article with a defined

LSP in the context of mechanical engineering, 2) the division of separate parts of this article shows great care to explain every part that goes into researching the deformation, and 3) it is easy to discern the target audience for this text, as this article uses formulas, symbols for variables and constants, and a theoretical context which is mostly unknown to general public. All of these reasons will firstly be explored in the brief text analysis which will later be utilised to discuss translation solutions.

4. Text and translation analysis

4.1. Scientific text analysis

As previously mentioned in the previous chapter, this research covers a non-unified model exploring multiaxial plastic deformation. The main point of this work is to separate multiple forces influencing behaviours materials exhibit when put under mechanical, thermic, and time-dependent stress. By separating "time-dependent" and "time-independent" forces (Kurath and Jones 2001: 1), the authors are able to predict said behaviours of materials more accurately via equations separate into time-dependent and time-independent forces. It is important to analyse this text linguistically, as this can help finding various linguistic equivalents in the Croatian language to convey the same message and to be readable for the intended audience.

The topic and aim of this paper are already obvious in its chapter division. This paper contains an abstract, an introduction, and describes testing material and equipment used to observe material behaviour. The paper starts to display research and results and has this part divided into two following chapters: mechanical deformation, explaining various types of mechanical deformation, and time-dependent deformation as separate from mechanical deformation. The work continues with a discussion and ends with a short conclusion which summarises the discoveries upon examining the material behaviour under separated forms of deformation (cf. Kurath and Jones 2001: 17).

The content of chapters mostly governs the sentential syntax of the whole academic paper. In order to highlight differences between simple and complex sentences, the remaining clauses of complex sentences will be italicised. The text that would be translated and analysed for this master's thesis covers only the parts from "Abstract" to "Analytical Modeling and Baseline Experiments: Time Dependent Deformation". While complex sentences are common, the abstract of this paper also contains some simple sentences (ex. 1 and 2 (Kurath and Jones 2001: 1)):

1) The literature also suggests a similar scenario with regard to the damage accumulation.
2) Uniaxial, torsional and axial-torsional thermomechanical loadings are analyzed with three constraint conditions.

The pattern of simple sentences in the remaining chapters can be seen in the beginning of different paragraphs (ex. 3 (Kurath and Jones 2001 ibid.)):

3) At elevated temperatures time or rate dependent behavior may dominate the deformation. The typical isothermal experimental observations for cyclic deformation are changes in the yield strength and different strain hardening behavior *once the specimen has yielded*.

The chapter "Material and Testing Equipment" was heavily governed by simple sentences (ex. 4, 5, and 6 (Kurath and Jones 2001: 2)):

4) The material for all experiments was a low carbon hot rolled low-alloy steel with the following weight percent of alloying elements; 0.16%-C, 1.21%-Mn, 0.024%-P, 0.008%-S, 0.19%-Si, 0.02%-Ni, 0.01 %-Cr, 0.039%-AI, 0.07%- V.
5) A typical application for this steel is as the base metal in many welded structural applications.
6) Uniaxial samples were button head type specimens with a 15 mm gage length and an 8 mm gage diameter.

This sentential type also serves the informative function meant for this chapter and the information it contains. All the simple sentences focus on each part of the material(s) and equipment meant to use for testing. With this in mind, it would be problematic to try writing this chapter using the complex sentences and bulking information about multiple materials and equipment (ex. 7):

7) Uniaxial samples were button head type specimens with a 15 mm gage length and an 8 mm gage diameter, *biaxial specimens were tubular, with a gage length of 30 mm, an outer gage diameter of 18 mm and inner diameter of 12.7 mm*, and *microstructural examination of the test samples revealed a banded microstructure found in many rolled steels*.

This complex sentence (made up of originally simple sentences from the source text) bulks the information unnecessarily and makes it more complicated to read and understand the information clearly. Some of the only cases when complex sentences would be acceptable in context of chapters in other scientific work with similar content would be when using adverbial clauses of purpose, result, and/or cause (ex. 8 (Kurath and Jones 2001: 2)), with placeholder sentence beginnings like "It is [*adj*.] to [*v*.] [*that-clause*]" (ex. 9 (Kurath and Jones 2001 ibid.)), and using -ing clauses (ex. 10 (Kurath and Jones 2001 ibid.)):

8) Examination of axial and torsional mechanical properties will be employed *to substantiate this observation.*
9) It is reasonable to assume *that similar material behavior would be seen in the transverse and longitudinal directions*.
10) Uniaxial testing was conducted *using a 100 kN capacity servohydraulic load frame with a closed-loop computer control system.*

The chapter "Analytical Modeling and Baseline Experiments: Mechanical Deformation" does not show any specific sentence syntax patterns. Most common sentence types were complex sentences, but that again depended on the same issue regarding the usage of complex and/or simple sentences. It needs to be stressed again that simple sentences are used to emphasise separate pieces of information necessary to memorise within the scope of work. However, there is one syntactic formation worth mentioning within the context of this chapter – the way sentences are interjected with formulas (ex. 11 (Kurath and Jones 2001: 3))

11) The most straight forward term is the thermal strain, where the following equation was utilized, $d\varepsilon_{kl}^{\Delta T} = \alpha T\delta_{kl} + T\left(\frac{d\alpha}{dT}\right)dT\delta_{kl}$ where dT is a change in temperature, α is the coefficient of thermal expansion, and δ_{ij} is the Kronecker delta.

The entirety of this chapter showcases this pattern where colon is not used to divide the sentence and the formula, as if the formula is merely an extension of this sentence. Some of the formulas are ends of sentences, but in the case of ex. 11, it was followed by further explanation of variables and constants. The graphic organisation of this type of information will show to be slightly problematic for translation, as formulas stand with a bigger font separate from other sentence parts (see figure 1).

THERMAL DEFORMATION – The most straight forward term is the thermal strain, where the following equation was utilized,

$$d\varepsilon_{kl}^{\Delta T} = \alpha \, dT \delta_{kl} + T \left(\frac{d\alpha}{dT} \right) dT \delta_{kl} \qquad (3)$$

where dT is a change in temperature, α is the coefficient of thermal expansion, and δ_{ij} is the Kronecker delta. The

Figure 1: graphic structure of sentences containing formulas (Kurath and Jones 2001: 3)

While sentential syntax analysis is important to examine what sentence structure is effective when providing information, phrasal syntax is crucial to find equivalent expressions within phrasal level. First thing to notice already in the beginning of this article, which can be found in multiple sentences, is usage of an inanimate subject (ex. 12 and 13 (Kurath and Jones 2001: 1), ex. 14 (Kurath and Jones 2001: 3)):

12) *Thermomechanical deformation* poses several challenges [...].
13) [...], *most materials* display temperature dependence [...].
14) *Figure 1* displays the temperature variation of these two constants, [...].

The most common pattern of phrasal syntax in this article is also the usage of passive (ex. 15 and 16 (Kurath and Jones 2001: 1), 17 (Kurath and Jones 2001: 2), and 18 (Kurath and Jones 2001: 4)):

15) [...] recent modifications of the Armstrong-Frederick type plasticity formulations *are utilized* as a basis for the current model.
16) The choice [...] *is based on* the notion that [...].
17) Axial thermomechanical experiments *were conducted* considering three axial strain constraint cases; [...].
18) Implications of the amplitude dependent non-Masing character of the equations *has been investigated* for rate independent deformation [21].

Occasionally, this paper uses nominalisations in order to avoid excessive use of verbs (ex. 19 (Kurath and Jones 2001: 2), 20 (Kurath and Jones 2001: 4), and 21 (Kurath and Jones 2001: 7)):

19) A typical *application* for this steel is as the base metal in many welded structural applications.
20) A major *contribution* to the modification of the Armstrong Frederick hardening relation was made by Chaboche et al. [2,3].
21) While the choice of this constant has *implications* in the current analysis, [...].

While there are not a lot of specifics regarding the text analysis and the syntax, it would be beneficial for this thesis to take the terminology of this paper into consideration and talk about it separately in the context of text analysis. Covering terminology in regards to translation of this scientific text would aid consistent terminology to ensure the proper quality of the translation.

4.2. Terminological considerations within the context of the sample text and translation solutions

Although linguistic considerations for this translation reign in sentential and clausal organisation, terminological considerations are crucial in order to maintain terminological consistency of STT. The most notable terminological issues in this work included the interplay between the three following terms: deformation, stress, and strain. Other terminological considerations will be discussed later with the progression of terminology and meaning of the three aforementioned terms. In order to aid the later translation, it would be useful to look at how the three basic terms are defined in English literature discussing deformation. The most straightforward definitions and descriptions of these notions are given by E. J. Hearn in his work *Mechanics of Materials 1* (1997).

When discussing deformation, the first notions that come along are definitions of simple stress and strain. These notions first stem from material undergoing any kind of external force (cf. Hearn 1997: 1). Stress is in this context defined as an internal counterforce equal to the aforementioned compression and can be calculated by dividing the amount of load (P) and surface area affected (A) (cf. Hearn 1997: 2). As bar is subjected to said stress and direct external load, a strain will be produced, which is a product of division between the change in length and original length (cf. Hearn 1997: 1). In this sense, strain is "a measure of the deformation of the material and is non-dimensional, i.e. it has no units; [...]" (Hearn 1997: 1).

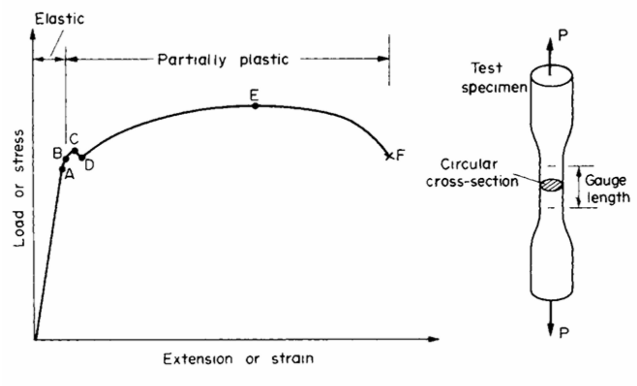

Fig. 1.3. Typical tensile test curve for mild steel.

Figure 2: the stress-strain curve (Hearn 1997: 4)

This theoretical consideration helps understanding the relationship between stress and strain, as they do share a dependency depicted in graph (see figure 2), which will be the main influence on the translation of these terms. Furthermore, their appointed symbols in physics would likely facilitate the search for Croatian equivalent terms. Stress is marked by a Greek letter σ, while strain is marked by ε (cf. "Notation" in Hearn 1997). Although finding these physical units in the Croatian language would in theory help finding a proper translation solution, this turned in practice to cause more problems: while the Croatian term for stress (σ) is *naprezanje* (example 22 a), Kurath and Jones 2001: 3, and b)), the (ε) Croatian equivalent for strain would be *deformacija* (cf. Vnučec). The reason why this translation for strain would be problematic is because of the need to differentiate between the following two English terms terminologically in Croatian as well: deformation and strain. Although strain is supposed to stay *deformacija*, the issue at hand would be the translation of the title containing the term "deformation", especially as "deformation" and "*deformacija*" are utilised in titles of scientific texts in their respective languages (example 23 a), Kurath and Jones 2001, and b), Ajvaz 1969).

22) a) **Stress** levels chosen at a given temperature were approximately a third to half of the anticipated 0,2 % offset yield strength.

b) Razine **naprezanja** odabrane na danoj temperaturi bile su približno trećina do polovice od očekivanog pomaka snage razvlačenja od 0,2 %.

23) a) Multiaxial Thermomechanical **Deformation** Utilizing a Non-Unified Plasticity Model

b) *Mjerenje **deformacije** i naprezanja u strojarstvu i građevinarstvu*

Deformacija does not commonly appear as a key word in titles of works and scripts meant for college students in Croatia (example 24 a), Plazibat et al. 2019, and b), Vnučec).

24) a) *Nauka o čvrstoći*

b) *Čvrstoća*

However, it can be seen in the example 22 b) that "*deformacija*" obviously can be used in titles in the same manner as "deformation". Although this would in theory also make easier the decision which term (strain or deformation) would be translated as *deformacija*, it is hard to ignore the fact that *deformacija* is commonly used to denote the same thing as strain and stands in the same context with stress and stress-strain curve (examples 25 a), Kurath and Jones 2001: 1, and b), Vnučec, 26 a), Kurath and Jones 2001: 4, and b), Vnučec).

25) a) In general a plastic **strain** is the result of these calculations with no differentiation between rate dependent and independent contributions.

b) *Radi jednostavnosti definiranja komponenti* ***deformacije*** *u točki tijela uvodi se ravninski model, slika.*

26) a) **strain** tensor

b) *tenzor* ***deformacije***

To add to the previous two examples, suggestions have been made that an English equivalent of "*deformacija*" would be in some cases "deformation" and in some "strain" (Struna). Although these are two different terms synonymous to "*deformacija*" and their definitions differ ("*poremećaj u razvoju nastao djelovanjem mehaničkih sila*" compared to "*bezdimenzijska veličina kojom se mjeri promjena oblika čvrstoga tijela pod djelovanjem sile*" (Struna)), all of these problems regarding a division of "deformation" and "strain" into two distinct Croatian terms get complicated. Although there are more sources backing equivalence between "strain" and "*deformacija*" unlike "deformation" and "*deformacija*", it would not make sense for the title that utilises the term "deformation" to get a different term such as *izobličenje*, because there is so far no evidence to justify the use of *izobličenje* and other related synonyms. Furthermore, it would not be fair to assume lack of creativity in translating "deformation" in the way that the translation pair "strain" – "*deformacija*" would be kept intact because the existence of said creative translation cannot guarantee the use of the term in a target language: "scientific discourse indeed seems to be based on tightly prestructured frames of reference [...]" (Krüger 2015: 43). This in turn makes scientific and technical texts "much more tightly structured and more stable" (Krüger 2015: 48).

A decision upon differentiation of translation of "deformation" and "strain" is to use the terms "*deformacija*" and "*rezultat naprezanja*" respectively. *Deformacija* is suitable in the context of the title of the said paper (example 27 a) and b)) and can be used as a reference to one part of materials science.

27) a) Multiaxial Thermomechanical **Deformation** Utilizing a Non-Unified Plasticity Model

b) *Ispitivanje višeosne termomehaničke **deformacije** primjenom neobjedinjenog modela plastičnosti*

The reason why strain could be *rezultat naprezanja* as an alternative stems from the aforementioned relation between stress and strain, as strain of a material is the visible result of applied stress. The solution to paraphrase what "strain" is into Croatian could be seen as a conservative solution to this translation problem, as this paraphrase is contained within the limit of Croatian terminology regarding the topic of deformation (example 28 a) and b)).

28) a) A 12.7 mm gage length high temperature extensometer with a ±5% full scale output was used to measure **strains**.

b) *Za mjerenje **rezultata naprezanja** korišten je visokotemperaturni ekstenzometar mjerne duljine 12,7 mm s izlazom pune skale ± 5 %.*

Of all the translation problems faced during the process, the terminology and determining the most appropriate and, if nothing else, the least problematic expressions for *strain* and *deformation* proved to be the hardest challenge.

4.2.1. The impact of terminology and theoretical context on discerning the intended target audience

Of all the factors meant to determine the audience intended for reading this article, the most notable one would most likely be the usage of terminology and/or explanation about it given, or lack thereof. This section gives a brief outlook on how the remaining terminology in this sample text helps in conclusion on proper translation and/or amount of explication.

The most obvious sign of the intended target audience would be the title itself (example 29 a)). Multiple scientific and/or technical terms (multiaxial, thermomechanical, plasticity model) contained in this title could be problematic to read for an average reader with no technical knowledge in this field. Furthermore, attempting to paraphrase the title even in the source language would prove to be insufficient to aid understanding of this article's topic (example 29 b)). To add to this, this paraphrase would also go against the proper terminology in this field.

29) a) Multiaxial Thermomechanical Deformation Utilizing a Non-Unified Plasticity Model

b)* Thermal and Mechanical Deformation on Multiple Axis Utilizing a Non-Unified Model of Plasticity

Another concern for this text would be the lack of explication of multiple terms present in the paper. Although discussing the meaning of these terms is out of scope of this section, enlisting some of them would demonstrate the strictly scientific and/or technical nature of this article (example 31 a), b), c), d), e), and f)).

30) a) creep

b) time-(in)dependent / rate-(in)dependent

c) Armstrong-Frederick model

d) uniaxial, biaxial, multiaxial

e) torsional, tensile

f) closed-loop computer

Due to the presence of these remaining terminological issues and the lack of explication of these terms and/or theories, it is easy to determine that the main target audience would be other mechanical engineers specialising in materials science and students with some previous knowledge in physics and/or deformation. Although all of the aforementioned terms and/or theories would be easily explained by providing footnotes, the complexity of the article's title would most likely not even attract the common reader in the first place. Additionally, since this paper was published in a scientific magazine (*SAE Transactions*), common reader would be least likely to look up and read this paper.

4.3. Translation solution analysis

Since chapter 4.1. attempts to follow the order of clausal and phrasal syntax present in the sample text during the text analysis, this chapter will follow the same order. That way it is ensured that the textual and linguistic attributes are analysed in the order from larger linguistic units to smaller linguistic units.

Most of the sentences from the source text would be syntactically translated into target language the same way, since some of the linguistic hallmarks of English are compatible with those of Croatian. The same can also be said for the sentential order of some of the complex sentences (examples 31 a) and b), 32 a) and b)).

31) a) Thermomechanical deformation poses several challenges in the sense that material properties change with temperature, and at higher temperatures time dependent phenomena such as creep and/or stress relaxation are active deformation mechanisms.

b) *Termomehanička deformacija predstavlja nekoliko izazova jer se svojstva materijala mijenjaju s temperaturom, a na višim temperaturama vremenski ovisni fenomeni poput puzanja i/ili smanjenja naprezanja aktivni su mehanizmi deformacije.*

32) a) For isothermal rate independent analysis it is conventional to decompose the strains into elastic and plastic components, henceforth referred to as mechanical strains.

b) *Za izotermalnu analizu neovisnu o brzini uobičajeno je dekomponirati rezultate naprezanja na elastične i plastične komponente koje se dalje nazivaju rezultatima mehaničkog naprezanja.*

Any change in sentential and/or phrasal order would in this case be due to style preferences of a translator. However, many of the complex sentences in this text had to undergo reorganisation to fit the standard Croatian (example 33 a), b)).

33) a) A 12.7 mm gage length high temperature extensometer with a ±5% full scale output was used **to measure strains**.

b) ***Za mjerenje rezultata naprezanja*** *korišten je visokotemperaturni ekstenzometar mjerne duljine 12,7 mm s izlazom pune skale ± 5 %.*

Rearranging clauses within a sentence could be comparable with attempting to split strings of complex sentences into simpler units, considering the skopos and the function of scientific and technical texts and STT discussed in section 2.2.2., as this rearrangement facilitates the readability of the text in the target language. Additionally, the clause of purpose "to measure strains" in an example 32 a) has been changed into an adverbial of purpose in Croatian example 33 b) ("*za mjerenje rezultata naprezanja*"), which turns this sentence from complex to simple. Additionally, this is an instance of nominalisation in Croatian, but English nominalisations and their solutions in Croatian language will also be discussed later in this chapter. Once again, turning a complex sentence into a simple one makes it easier to differentiate the main action or event in a sentence of a scientific and technical text.

To add before the discussion of phrasal syntax, it is important to see the solutions to the problem of inserted formulas, which were mostly introduced by a comma in a previous sentence. As discussed in the text analysis, this is not only a grammatical problem, but also a graphic problem with sentence and formula organisation, as the formulas have been inserted as figures in the original text. Two solutions for this problem were used in translation. The first solution used to adjust to the Croatian standard was to end the sentence in that part of the paragraph and use the phrase "*prikazano ispod*" (examples 34 a) and b), 35 a) and b)):

34) a) The addition of temperature variation usually leads to consideration of a thermal strain driven by the coefficient of thermal expansion summarized in the following expression, $\varepsilon_{kl} = \varepsilon_{kl}^{\Delta T} + \varepsilon_{kl}^{E} + \varepsilon_{kl}^{P}$.

b) *Dodavanje temperaturnih varijacija obično dovodi do razmatranja rezultata toplinskog naprezanja uzrokovanog koeficijentom toplinskog širenja sažetim u izrazu* ***prikazanom ispod****.* $\varepsilon_{kl} = \varepsilon_{kl}^{\Delta T} + \varepsilon_{kl}^{E} + \varepsilon_{kl}^{P}$

35) a) They proposed that the total backstress be composed of a number of additive parts, with each part of the backstress following an Armstrong-Frederick format, $\alpha_{kl} = \sum_{i=l}^{M} \alpha_{kl}^{(i)}$

b) *Predložili su da se ukupno dugotrajno unutarnje naprezanje sastoji od niza aditivnih dijelova pri čemu svaki dio dugotrajnog unutarnjeg naprezanja slijedi Armstrong-Frederickovu formulu* ***prikazanu ispod****.* $\alpha_{kl} = \sum_{i=l}^{M} \alpha_{kl}^{(i)}$

The second solution was simpler, as some of source sentences allowed for a simpler phrase such as "*sljedeća jednadžba*" (examples 36 a) and b)):

36) a) It is possible to further partition the strains by using the **ensuing form**, $\varepsilon_{kl} = \varepsilon_{kl}^{\Delta T} + \varepsilon_{kl}^{E} + \varepsilon_{kl}^{MP} + \varepsilon_{kl}^{CP}$.

b) *Moguće je dodatno podijeliti rezultate naprezanja korištenjem* ***sljedeće formule:*** $\varepsilon_{kl} = \varepsilon_{kl}^{\Delta T} + \varepsilon_{kl}^{E} + \varepsilon_{kl}^{MP} + \varepsilon_{kl}^{CP}$.

The phrasal syntax analysis of this translation shows in some cases the conservation of original forms in the source language, while the others had to undergo certain changes. However, there are instances where most or all of the solutions conserve the original, e.g. with the use of inanimate subject (examples 37 a) and b), 38 a) and b), 39) a and b)).

37) a) **Thermomechanical deformation** poses several challenges in the sense that material properties change with temperature, and at higher temperatures time dependent phenomena such as creep and/or stress relaxation are active deformation mechanisms.

b) ***Termomehanička deformacija*** *predstavlja nekoliko izazova jer se svojstva materijala mijenjaju s temperaturom, a na višim temperaturama vremenski ovisni fenomeni poput puzanja i/ili smanjenja naprezanja aktivni su mehanizmi deformacije.*

38) a) Even within the realm of rate insensitive behavior, **most materials** display temperature dependence even for basic properties such as the linear elastic modulus and yield strength.

b) *Čak i kod ponašanja neosjetljivog na brzinu* ***većina materijala*** *pokazuje temperaturnu ovisnost čak i za osnovna svojstva kao što su linearni modul elastičnosti i snaga razvlačenja*.

39) a) **Figure 1** displays the temperature variation of these two constants, and the shear modulus calculated assuming an elastic Poisson's ratio v=0.3.

b) ***Slika 1*** *prikazuje temperaturnu varijaciju ovih dviju konstanti i modul posmika izračunat uz pretpostavljen elastični Poissonov omjer v = 0,3*.

Passive constructions, on the other hand, had to undergo two types of translation solutions. Although some changes could be ascribed to the style preferences, a lot of changes stem from the fact that most verbs in Croatian don't allow natural passive constructions. The most common solution to passive is use of verbal construction with "*se*" (example 40 a) and b)).

40) a) Due to recent success modeling many time-independent plastic deformations, recent modifications of the Armstrong-Frederick type plasticity formulations **are utilized** as a basis for the current model.

b) *Zbog nedavnog uspješnog modeliranja mnogih plastičnih deformacija neovisnih o vremenu* ***koriste se*** *nedavne modifikacije Armstrong-Frederickovog tipa modela plastičnosti kao osnova za trenutni model*.

Some passive constructions are allowed in Croatian as well, provided they stem from words that may grammatically take such verb form, such as "*podvrgnuti*", "*koristiti*", etc. (examples 41 a) and b), 42 a) and b)).

41) a) Many engineering components **are subjected to** cyclic thermal and mechanical loadings during their service life, and are considered under the general moniker of thermomechanical loading.

b) *Mnoge inženjerske komponente* ***podvrgnute su*** *tijekom svog rada cikličkim toplinskim i mehaničkim opterećenjima za koje se smatra da spadaju pod općim nazivom termomehaničkog opterećenja*.

42) a) An induction heater **was used** to heat all tubular specimens.

b) *Za zagrijavanje svih cjevastih primjeraka* ***korišten je*** *indukcijski grijač.*

Although this thesis showed a translation of one clause resulting in its nominalisation in Croatian, one can notice that it is common to approach the translation of English nominalisation into Croatian conservatively, i.e. to keep the nominalisation in the target language as well (examples 43 a) and b), 44 a) and b)). However, sometimes more liberal translation results in the elimination of the nominalisation (examples 45 a) and b)).

43) a) A major contribution to the modification of the Armstrong Frederick hardening relation was made by Chaboche et al. [2,3].

b) *Veliki* ***doprinos*** *modifikaciji Armstrong-Frederickove relacije otvrdnjavanja dali su Chaboche et al. [2, 3].*

44) a) While the choice of this constant has implications in the current analysis, its impact will be most pronounced when the model is cycled to allow ratcheting or cyclic stress relaxation.

b) *Iako izbor ove konstante ima* ***implikacije*** *u trenutnoj analizi, njezin će utjecaj biti najizraženiji kada se model ciklički mijenja kako bi se omogućilo ubrzanje ili cikličko popuštanje naprezanja.*

45) a) A typical application for this steel is as the base metal in many welded structural applications.

b) *Uobičajeno* ***se*** *ovaj čelik* ***primijenjuje*** *kao osnovni metal u mnogim zavarenim konstrukcijama.*

Seeing the sentential and phrasal behaviours and their change during the translation process into Croatian shows here how the necessity to make information as approachable and natural-sounding as possible in a target language governs the overall translation product both on phrasal and sentential level. Although the Croatian translation demonstrates the possibility of both conservative and free translation keeping the original phrasal syntax, a lot of complex sentences had to undergo rearrangement.

5. Conclusion

This master's thesis finds its importance in the context of globalisation and necessity for improved information exchange, especially in scientific and technical communication, texts, and/or translation.

The translation practice and business has existed since the languages themselves existed. While this practice has been preserved to this day, the research and thought about this process is relatively new and stems from the need for understanding how translation process works and how it results in a translation product. The new emerging field of research, i.e. translation studies, aims to analyse the bridges between the paradigms of a source language and source text and a target language and target text and to see how this information of a source text flows into a target text without losing the intended message. Although translation studies itself is relatively new, there have always been attitudes towards different types of documents and translations in regards to how they are to be written and translated. The biggest difference lies in a self-proposed dichotomy between literary and scientific and technical translation. While literature and literary texts demand more creativity, overall world knowledge, and talent to write and remember idiomatic phrases and metaphors, scientific and technical translation is almost exclusively denotative and does not require deep thought into form, but rather a proper, adequate transfer of information from a source language to target language. However, these differences between literary and scientific and technical translation caused a negative bias towards scientific and technical translation. This thesis aimed to prove that the negative bias is not justified by representing how many factors there are to scientific and technical translation that cannot be overlooked over simplistic notion of equivalence.

Scientific and technical translation has previously not received much attention from scholars, mostly because of the previously mentioned negative bias. Contrary to the mentioned bias, the researchers in the field of scientific and technical translation such as Ralph Krüger and other contributors to works published by the *American Translators Association* are proving that this field can be as interesting and as difficult as other types of texts and translations. Although scientific and technical translation is mostly overlooked by scholars, scientific and technical translation and technical communication still have their own rules that stem from a long-term experience from experts in this field. These rules can be seen in the way text is organised, written, and/or translated, in the purpose of the technical text and/or translation, and in the target audience intended to read the said technical text and/or translation. It is easy to notice how the style and language of the scientific and technical texts and translations is impacted by language for special purpose (LSP) dictating the terminological density and clarity of content, which is, like everything else, dependent on the target audience intended to read the scientific and technical translation. To add to this, the purpose of the text also can be influenced by the intended target audience and can impact the language and style of the translation, but the commonplace purpose of this type of translation is to be informative and provide new information about an already known subject. The target audience of this type of translation, however, depends solely on the reader's previous knowledge, which can prove to be the most challenging factor to a translator who rarely has contact with the target audience and their knowledge.

The text analysis helps understanding what the exact textual genre and topic of a piece of text are. Regarding the genre and the topic aids understanding of the purpose and the target audience of the text, both of which are important considerations for a translation. The sample text in question discusses deformation within the context of mechanical engineering. This paper attempts to estimate the stress-strain curve more accurately by separating different deformation processes and examining the material behaviour when undergoing these processes. This text does not have too many complicated linguistic attributes and all of them would have their Croatian grammatical equivalent. However, the terminology of this paper proved to be complicated, especially when estimating the difference between "deformation" and "strain" and the relationship between "stress" and "strain". After finding a solution to this problem, the remaining terminology helped me to pinpoint who the target readers would be for this article, especially with the formation and terminology of the article's title.

Since the target audience would be other professionals in the field of materials science, scientists, and students in mechanical engineering, this notion would also govern the way the text would be translated. Assuming their level of previous knowledge, further explanations of theory and terminology would not be necessary, meaning the length of the original text in its translation would be maintained. However, the real question of translation of a scientific and technical text would be grammar and syntactical organisation, i.e. which sentences maintain their original structure and/or phrases and which sentences would undergo sentential rearrangement, paraphrase, and swapping phrasal units. Translating this article demonstrated that it is possible both to use translation that faithfully follows the grammatical structures of English and to have sentences and phrases undergo necessary changes.

No matter which translation solutions are considered in the translation process, the main goal is to always maintain Herman's aforementioned stylistic attributes of clarity, concision, and correctness (cf. 1993: 13 – 19). Even without the regard of this piece of translation theory regarding STT, the translator would very likely find it natural to produce a clear translation that would not leave unnecessary questions unanswered.

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7. Appendix

7.1. Source text

2000-01-0782

Multiaxial Thermomechanical Deformation Utilizing a Non-Unified Plasticity Model

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ABSTRACT

The ability to model inelastic deformation is of practical interest in many design applications, especially with the current emphasis on lighter weight structures and com ponents operating at higher temperatures. Thermomechanical deformation poses several challenges in the sense that material properties change with temperature, and at higher temperatures time dependent phenomena such as creep and/or stress relaxation are active deformation mechanisms. Due to recent success modeling many time-independent plastic deformations, recent modifications of the Armstrong-Frederick type plasticity formulations are utilized as a basis for the current model. The choice to implement a non-unified model is based on the notion that distinct or independent mechanisms govern time dependent and independent plastic deformations. The literature also suggests a similar scenario with regard to the damage accumulation. Furthermore, it was deemed desirable to maintain the tensoral nature of both time-independent and “creep” stress-strain behavior especially for more complex multiaxial thermomechanical loadings such as those that may be encountered when analyzing residual stresses resulting from welding. A Sherby-Dorn creep stress power law relationship is utilized to model time-dependent deformation, along with a separate non-translating creep yield surface. Uniaxial isothermal experiments are employed to fit the modeling constants. Uniaxial, torsional and axial-torsional thermomechanical loadings are analyzed with three constraint conditions. Additional isothermal relaxation tests are examined to verify the basic concepts of the model. Omission of an adequate primary creep model is seen to inhibit the predictive capability at some temperature regimes, but the overall qualitative capabilities of the model are in agreement with the experimental results.

INTRODUCTION

Many engineering components are subjected to cyclic thermal and mechanical loadings during their service life, and are considered under the general moniker of thermomechanical loading. Even within the realm of rate insensitive behavior, most materials display temperature dependence even for basic properties such as the linear elastic modulus and yield strength. At loading levels greater than the yield strength, most alloyed metals dis play rate insensitivity at room temperature. These experimental observations have been the basis for the development of many rate independent plasticity algorithms. The Armstrong-Frederick [1] model, utilizing modifications proposed by Chaboche et al. [2,3], and further enhanced by Ohno et al [4] and Jiang[5] has been Identified by the authors as being a suitable basis for modeling rate independent plastic deformation [6,7].

At elevated temperatures time or rate dependent behavior may dominate the deformation. The typical isothermal experimental observations for cyclic deformation are changes in the yield strength and different strain hardening behavior once the specimen has yielded. The exact definition of elevated temperature may vary for different alloy systems, but its onset will be approximately a third to a half of the melting temperature in °K. Even within the context of steady state isothermal creep, deformation mechanism maps proposed by Ashby, et al [8,9] illustrate some of the complexities involved in the definition of time dependent deformation.

Many previous researchers [10-16] have successfully utilized unified theories to model thermomechanical deformation. The unified models often consider the dominance of either mechanical or time dependent plastic deformation when formulating the state variable(s). In general a plastic strain is the result of these calculations with no differentiation between rate dependent and independent contributions. Perhaps it should be noted that Coffin's [17] original use of plastic strain in the sense that it currently embodies in the fatigue literature was for elevated temperature experiments. Halford, Manson, et al. [18, 19] developed a strain range partitioning technique to evaluate damage when a specimen was subjected to both cyclic reversals and creep hold times. They observed that the cyclic damage could not be characterized by plastic strain alone. While the extension of strain range partitioning or any other damage evaluation technique is beyond the scope of this paper, examination of separation of the variables within the general category of plastic strain for the deformation modeling will be the focus of the ensuing presentation. Mechanical and steady state creep plastic strains due to dislocation creep, which is a diffusion driven mechanism, will be considered in this preliminary investigation. Further more, the tensoral nature of the strains will be maintained to allow the method to consider general multiaxial stress strain states in a more straightforward manner.

MATERIAL AND TESTING EQUIPMENT

The material for all experiments was a low carbon hot rolled low-alloy steel with the following weight percent of alloying elements; 0.16%-C, 1.21%-Mn, 0.024%-P, 0.008%-S, 0.19%-Si, 0.02%-Ni, 0.01 %-Cr, 0.039%-Al, 0.07%- V. A typical application for this steel is as the base metal in many welded structural applications. Uniaxial and biaxial test samples were machined from one inch thick plate stock with the longitudinal direction coinciding with the rolling direction. Uniaxial samples were button head type specimens with a 15 mm gage length and an 8 mm gage diameter. Biaxial specimens were tubular, with a gage length of 30 mm, an outer gage diameter of 18 mm and inner diameter of 12.7 mm. Microstructural examination of the test samples revealed a banded microstructure found in many rolled steels. Micrographs taken of the test samples' transverse and longitudinal cross-sections revealed similarly oriented layers of ferrite and pearlite. It is reasonable to assume that similar material behavior would be seen in the transverse and longitudinal directions. Examination of axial and torsional mechanical properties will be employed to substantiate this observation.

Uniaxial testing was conducted using a 100 kN capacity servohydraulic load frame with a closed-loop computer control system. Data acquisition was handled by a 32-bit data acquisition and signal interface between a computer and the load frame. A 12.7 mm gage length high temper ature extensometer with a ±5% full scale output was used to measure strains. The extensometer rods were ground from quartz into a point which fit into the small indentations on the side of the test sample. Isothermal temperature control was obtained by using a 2.5 kW radiant heat ceramic furnace in conjunction with a PID-loop temperature controller. Type K thermocouples were used to measure temperature at three intervals along the gage length of the test sample. One thermocouple was used for control, with the other used to monitor the temperature variation along the test sample. Temperature variations along the gage length were kept within ±5°C. For uniaxial thermomechanical testing the radiant furnace was replaced with a 5 kW induction heater operating at approximately 250 kHz. The induction coil utilized was designed so that the temperature variation along the sample's gage length was within ±5°C. Multiple thermo couples were positioned at various locations within the gage section to verify this.

For the biaxial tests, a servohydraulic tension-torsion load frame was used with an axial load capacity of 445 kN and a torsional load capacity of 5500 N-m. A closed loop control system similar to the one utilized for the uniaxial tests was used for control and data acquisition. Biaxial strains were measured using a 25.4 mm gage length high temperature extensometer capable of mea suring axial and torsional strains. Full scale output for the extensometer was ±5% in both the axial and torsional strains. An induction heater was used to heat all tubular specimens. Again, type K thermocouples in conjunction with a PID-loop temperature controller were used to monitor and regulate temperature. A coil design procedure similar to that used for uniaxial thermomechanical experiments was employed.

Axial thermomechanical experiments were conducted considering three axial strain constraint cases; totally constrained, partially constrained, and overly constrained. For each specimen, a coefficient of thermal expansion was measured by recording the unconstrained thermal deformation associated with a known temperature change and performing a linear regression on the resulting data. Temperature ranges of 100 to 400°C and 100 to 600°C were imposed utilizing heating and cooling rates of 100°C per minute for all tests. The lower temperature boundary of 100°C was chosen based on the fact that air cooling made it impossible to attain temperatures below 100°C for the aforementioned cooling rates. The total maximum axial strain range on the sample would be 50% less than or greater than the maximum thermal strain range during a cycle for the partially constrained and overly constrained cases respectively. For torsional thermomechanical tests, the constraints considered in an axial sense effectively disappear due to the absence of thermal expansion effects on torsional deformations, creating an unconstrained situation. However, by imposing axial pseudo-constraints, where the torsional strain inputs are the von Mises equivalents oof the axial thermal strain associated with some temperature change and constraint condition, it is possible for the torsional mechanical response to be observed within the context of a constrained thermal cycle. For purely torsional thermomechanical tests, strain limits were considered to be the von Mises equivalents of corresponding uniaxial strain histories. Temperature ranges and heating or cooling rates similar to the ones considered in the axial thermomechanical experiments were investigated. All tests conducted had their thermal and mechanical strain cycles out of phase with one another.

ANALYTICAL MODELING AND BASELINE EXPERIMENTS: MECHANICAL DEFORMATION

Due to the variety of experiments conducted, it is probably less confusing to introduce them as development of the theory proceeds. For isothermal rate independent analysis it is conventional to decompose the strains into elastic and plastic components, henceforth referred to as mechanical strains. The addition of temperature variation usually leads to consideration of a thermal strain driven by the coefficient of thermal expansion summarized in the following expression,

$$\varepsilon_{kl} = \varepsilon_{kl}^{\Delta T} + \varepsilon_{kl}^{E} + \varepsilon_{kl}^{P} \tag{1}$$

The superscripts ΔT, E i P refer to thermal, elastic and plastic strains respectively. Within the context of unified theories, the time dependent strains are often embedded in the same term as mechanical plastic strains. It is possible to further partition the strains by using the ensuing form,

$$\varepsilon_{kl} = \varepsilon_{kl}^{\Delta T} + \varepsilon_{kl}^{E} + \varepsilon_{kl}^{MP} + \varepsilon_{kl}^{CP} \tag{2}$$

While the nomenclature of the fourth term could be decomposed into primary, secondary and other creep components, only one term is shown in this Equation since only steady state creep due to dislocation climb will be considered in the ensuing analysis. In general the methodology is not limited to this decomposition. The mechanical plasticity algorithm [6, 7] requires an incremental solution. Due to changes in temperature even the linear elastic properties will change, hence an incremental solution for Equation 2 will be formulated.

THERMAL DEFORMATION – The most straight forward term is the thermal strain, where the following equation was utilized,

$$d\varepsilon_{kl}^{\Delta T} = \alpha\, dT\delta_{kl} + T\left(\frac{d\alpha}{dT}\right) dT\delta_{kl} \qquad (3)$$

Where dT is a change in temperature, α is the coefficient of thermal expansion, and δ_{ij} is the Kronecker delta. The Kronecker delta allows isotropic volumetric thermal strains to occur. For the experimental temperatures ranging from 20 to 700°C no phase changes are expected for the low carbon steel investigated, and the assumption of α being a constant was experimentally verified. Hence, the second term on the right hand side of Equation (3) was neglected. If the coefficient of thermal expansion was temperature dependent, then both terms might be important. The importance of the term may also depend on the solution technique utilized. It should be noted that this a is different from the similar symbol with subscripts used to represent the backstress term in the kinematic hardening algorithm.

ELASTIC MECHANICAL DEFORMATION - Mechanical elastic deformation is modeled incrementally by assum ing a homogeneous isotropic linear Hooke's law relation

$$\varepsilon_{kl}^{E} = \left(\frac{\sigma_{kl}}{2G}\right) - \left(\frac{v\sigma_{jj}}{E}\right)\delta_{kl} \qquad (4)$$

where E is the elastic modulus, *v* is Poisson's ratio, and G is the shear modulus. It is expected that the two moduli will change with temperature, but presently we assume that Poisson's ratio is a constant. Differentiation renders the following incremental format for the elastic deformation,

$$d\varepsilon_{kl}^{E} = \left(\frac{d\sigma_{kl}}{2G}\right) + \left(\frac{-\sigma_{kl}}{2G^2}\right)\left(\frac{dG}{dT}\right)dT - \left(\frac{vd\sigma_{jj}}{E}\right)\delta_{kl} - \left(\frac{-v\sigma_{jj}}{E^2}\right)\left(\frac{dE}{dT}\right)dT\delta_{kl} - \left(\frac{\sigma_{jj}}{E}\right)\left(\frac{dv}{dT}\right)dT\delta_{kl} \qquad (5)$$

The second, fourth and fifth terms are the result of the differentiation and consideration of the linear elastic material properties being a function of temperature. In general, the linear and shear modulus are related by the following equation,

$$G = \left(\frac{E}{2(1+v)}\right) \qquad (6)$$

Fully reversed stress controlled isothermal uniaxial and torsional only tests were conducted at temperatures of 20, 200, 300, 400, 500, 600, and 700°C to determine E and G. Stress levels chosen at a given temperature were approximately a third to half of the anticipated 0.2% offset yield strength. Figure 1 displays the temperature variation of these two constants, and the shear modulus calculated assuming an elastic Poisson's ratio *v* = 0.3. It appears that assuming Poisson's ratio to be temperature independent is not unreasonable. This observation eliminates the fifth term in Equation (5).

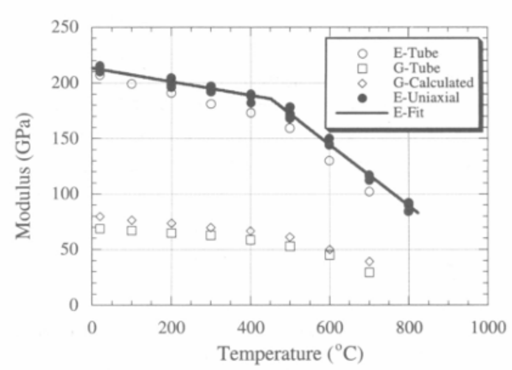

Figure 1. Representation of the linear elastic temperature dependent material properties.

A simple bilinear representation (Appendix I) of the axial modulus, E, versus temperature was deemed sufficient to model the linear elastic properties. This fit is not continu ous with regard to the first derivative. This may appear to be problematic regarding the second and fourth terms of Equation (5). But if a small enough time increment is chosen, it is inferred that they can be neglected in the ensuing analysis. In essence, each time step in the solu tion is considered to be an isothermal event by omitting the second and fourth terms. Due to the slow heating and cooling rates chosen, this is a reasonable assump tion. Faster heating and cooling rates would at some point result in temperature gradients in the radial direc tion of the specimen which are also not considered in this analysis.

PLASTIC MECHANICAL DEFORMATION - Without belaboring the merits of various rate independent plasticity models, the authors have chosen to implement an incremental format based on the Armstrong-Frederick [1] hypothesis. s. The algorithm will specify (i) the direction and (ii) the magnitude of the yield surface translation, and utilize the consistency condition to determine the hardening modulus. Due to the decomposition of the mechanical strains into elastic and plastic components, it is necessary to have a demarcation between these two types of deformation. Typically a yield function as shown in the following equation is employed,

$$f = (S_{kl} - \alpha_{kl}):(S_{kl} - \alpha_{kl}) - 2k_M^2 = 0 \quad (7)$$

With

$$S_{kl} = \sigma_{kl} - \frac{\sigma_{jj}}{3}\delta_{kl} \quad (7a)$$

Where k_M is the yield stress in simple shear, S_{kl} is the deviatoric stress tensor, and α_{kl} is the backstress tensor. For the purposes of this investigation, k_M is a constant at a given temperature, which implies only kinematic hardening is being considered. Without loss of generality, the normality flow condition [20] is used,

$$d\varepsilon_{kl}^P = \frac{1}{h}\langle dS_{mn} : n_{mn} - \sqrt{2}\frac{dk_M}{dT}dT\rangle n_{kl} \quad (8)$$

The prefix d denotes infinitesimal increment or differentiation. The quantities ε_{kl}^P and σ_{kl} represent plastic strain tensor and stress tensor respectively, while n_{kl} denotes the unit normal on the yield surface and is defined as follows.

$$n_{kl} = \frac{S_{kl} - \alpha_{kl}}{|S_{mn} - \alpha_{mn}|} \text{ (no summation over k, l)} \quad (9)$$

A colon between two tensors denotes their inner prod uct. The symbol < > denotes the MacCauley bracket (i.e. = 0.5 (x+Ixl)) and h is a scalar function often called the plastic modulus function. Again the second term within the brackets in Equation (8) reflects that the rate independent yield strength will change with tempera ture. This term will be ignored in the current numerical simulation. The quantity dp is generally called the equiv alent plastic strain increment and is defined as,

$$dp = \sqrt{d\varepsilon_{kl}^P : \varepsilon_{kl}^P} \quad (10)$$

A major contribution to the modification of the Armstrong Frederick hardening relation was made by Chaboche et al. [2,3], They proposed that the total backstress be com posed of a number of additive parts, with each part of the backstress following an Armstrong-Frederick format,

$$\alpha_{kl} = \sum_{i=l}^{M} \alpha_{kl}^{(i)} \quad (11)$$

The superscript bracketed term, (i), in general refers to the number of terms in the backstress expansion, M. Subsequent refinements to the model by Ohno and Wang [4] and Jiang [5] have resulted in the following form for the increment of each backstress part,

$$d\alpha_{kl}^{(i)} = c^{(i)}r^{(i)}\left(n_{kl} - \left(\frac{\left|\alpha_e^{(i)}\right|}{r^{(i)}}\right)^{x^{(1)}+1} L_{kl}^{(i)}\right)dp + c^{(i)}\left(n_{kl} + \left(x^{(i)}+1\right)\left(\frac{\left|\alpha_e^{(i)}\right|}{r^{(i)}}\right)^{x^{(1)}+1} L_{kl}^{(i)}\right)\frac{dr^{(i)}}{dT}dT \quad (12)$$

The following nomenclature is also useful,

$$L_{kl}^{(i)} = \frac{\alpha_{kl}^{(i)}}{\left|\alpha_e^{(i)}\right|} \text{ (no summation over k, l)}$$

And

$$\left|\alpha_e^{(i)}\right| = \sqrt{\alpha_{mn}^{(i)} : \alpha_{mn}^{(i)}} \text{ (no summation over i)} \quad (13)$$

When $x^{(i)} = 0$, the first line (i.e. dp term) of Equation (12) is identical to Chaboche's original isothermal rate independent model. The second term, albeit arbitrary, is a result of allowing only $r^{(i)}$ to be a function of temperature. Further discussion of this term will be pursued later. In the context of this paper, the material properties considered will be representative of cyclically stable response, and the material will be considered to be of the homogeneous isotropic Masing type, hence dk = 0 at a constant temperature.

Implications of the amplitude dependent non-Masing character of the equations has been investigated for rate independent deformation [21]. One characteristic of this model is that the backstress part will never go beyond a surface which has a radius of $r^{(i)}$ and is centered at the origin. Additionally, the surface is not permitted to rotate. This surface will be referred to as a limiting surface for a backstress part. It is essential to emphasize that the limiting surface in the current context should not be confused with other references to limiting surfaces such as those utilized for two surface models. For further discussion see Jiang and Kurath [7]. The consistency condition requires that during elastic-plastic deformation the stress state remains on the yield surface. In conjunction with Equations (7) and (8), the consistency condition results in the following expression for the plastic modulus function,

$$h = \sum_{i=l}^{M} c^{(i)} r^{(i)} \left(1 - \left(\frac{\left|\alpha_e^{(i)}\right|}{r^{(i)}} \right)^{x^{(i)}+1} L_{kl}^{(i)} : n_{kl} \right) \tag{14}$$

In order to characerize the baseline response of the test material, uniaxial strain-controlled incremental stepp tests [22] using maximum fully reversed strain amplitudes of 1.0% were performed at temperatures of 20, 200, 300, 400, 500, 600, and 700°C. Strain rates of 0.0001, 0.001, 0.01, 0.1, and 1.0% per second were investigated at each temperature. Representative outer loops of the uniaxial tests at 300, 500 and 700°C are shown in Figures 2 a-c. It is useful to note that use of the incremental step tests forces the material to respond as a Masing material. From these incremental step data, it was possible to determine a 0.05% offset yield strength. This offset is often used in plasticity modeling, and is not the standard method for determining the offset yield strength for uniaxial tensile tests. The increasing half of the outermost loop of an incremental step block was normalized to an origin corresponding to zero stress and strain. The stress and strain amplitudes of the curve were halved, effectively converting the first half of the loop to a pseudo-monotonic stress-strain curve.

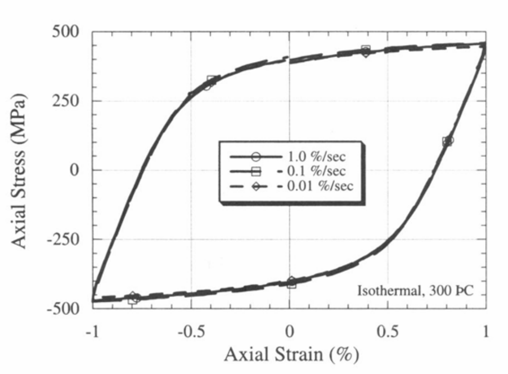

Figure 2a. Experimental outer loops of isothermal incremental step tests at 300°C.

At this juncture it is useful to forward the definition utilized to define experimental rate dependence or independence. Slavic and Sehitoglu [10] employ the strain rate versus the 0.05% offset yield strength as shown for the current material in Figure 3. The steeper slopes are associated with rate independent behavior or the dominance of mechanical plasticity, whereas the shallower slopes are considered to be controlled by time dependent phenomena. Torsional incremental step tests with a fully reversed amplitude of 1.732% engineering shear strain were conducted at the same temperatures and at shear strain rates of 0.001732, 0.01732, 0.1732, and 1.732% per second to compare rate dependency in shear to that observed in uniaxial tests. For purely torsional loading, the assumption that 1 .732% shear strain is equivalent to a uniaxial strain of 1.0% governed the comparative analysis. This assumption is based upon the fully plastic von Mises equivalency relationship. The results qualitatively mirror those shown in Figure 2. In general, moderately high strain rates and low temperatures are in a testing regime categorized as being rate independent. Conversely, higher temperatures and lower strain rates exhibit more rate dependency. In general, the material studied exhibited rate independence at temperatures below 350°C.

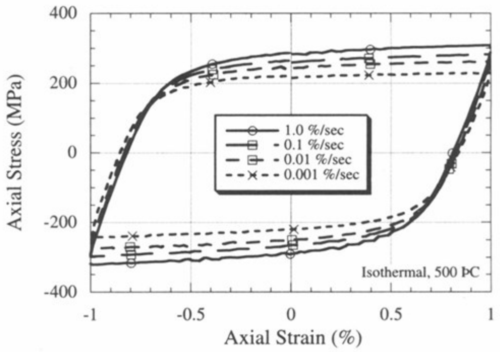

Figure 2b. Experimental outer loops of isothermal incremental step tests at 500°C

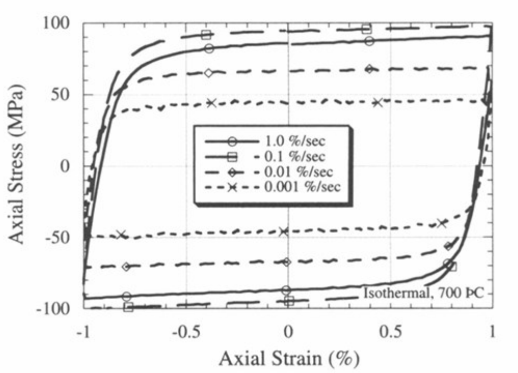

Figure 2c. Experimental outer loops of isothermal incremental step tests at 700°C.

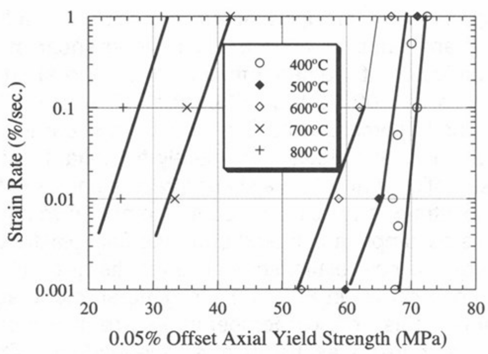

Figure 3. Methodology to determine rate dependence or independence of cyclic tests.

Due to the chosen decomposition of the plastic strains, it would be desirable to use only those tests deemed rate independent to fit the 0.05% offset yield strength and the plasticity variable $r^{(i)}$ at a given temperature. Details of fitting the plasticity parameters $c^{(i)}$ and $r^{(i)}$ are related in previous publications [7,23]. As was assumed in Equation 12, the $c^{(i)}$ terms, which in essence divide the stress strain curve in terms of plastic strain, were taken to be independent of temperature. Rate independent data (Figure 3) was utilized at temperatures less than 550°C. At temperatures greater than 550°C, truly rate independent tests could not be conducted due to experimental limitations, and the highest strain rate data were utilized to approximate the rate independent behavior. Figure 4 summarizes the plasticity variable, k ($k = \sigma_y/\sqrt{3} = t_y$), determined from both uniaxial and torsion only testing. A bilinear fit was deemed sufficient and is reported in Appendix 1. Again the discontinuity of the derivatives at the intersection of the two fits will limit consideration of the dT derivative term in Equation (8). There is an increase in this constant at approximately 300°C that is attributed to strain aging which will be neglected in this analysis

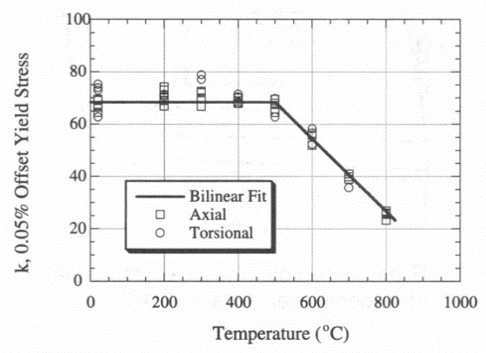

Figure 4. Temperature dependent representations of rate independent mechanical yield.

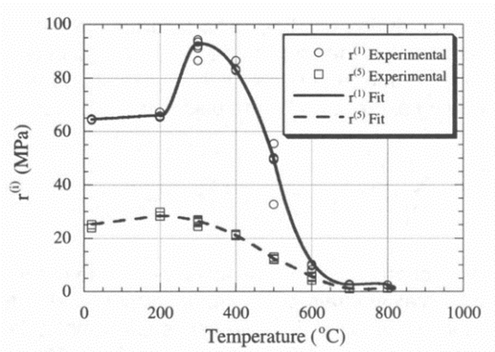

Figure 5. Temperature dependent representation of mechanical plasticity hardening parameter, $r^{(i)}$

Temperature dependence was accounted for in the determination of $r^{(i)}$. Figure 5 illustrates the temperature dependence of two $r^{(i)}$ terms. The effects of strain aging as evidenced by the hump in the $r^{(i)}$ curves between 200 and 400°C, were included in the formulation of this tem perature dependent scalar. Its effect is most prevalent in the $r^{(1)}$ curve, and diminishes as i increases as shown in Figure 5. In general the other curves fall in order as indicated by the ones shown. No one function was capable of fitting the variables $r^{(i)}$ over the entire range of temperature, and a best fit over a limited range of temperatures was employed. The functions and associated temperature ranges used to fit all the $r^{(i)}$ are summarized in Appendix 1. It was deemed important to force the different fits to ensure continuity at the temperature where the functions change form. No attempt was made to ensure continuity of any of the derivatives in this investigation. Ohno-Wang [24, 25] and Chaboche [26] have noted instances where neglecting the dT term in Equation 12 may be significant. They arbitrarily choose the following dT term to add to the dp portion of Equation 12.

$$+\left(\frac{\alpha_{kl}^{(i)}}{r^{(i)}}\right)\frac{dr^{(i)}}{dT}dT \tag{15}$$

If $x^{(i)} = 0$, their choice resembles the second term of the dT portion of Equation 12. However the temperature derivative term in Equation 12 will be ignored. The authors maintain that some of the difficulties they note are overcome by improvements to the model and employing a small increment in the solution technique. At this juncture, the formulation for mechanical deformation is complete. The lack of truly rate independent data cause the yield strength parameter, k, and $r^{(i)}$ to be overestimated at temperatures greater than 500°C. Resulting limitations will be discussed in a subsequent section. The hardening algorithm exponent, $x^{(i)}$, has been shown to have a value of approximately $x^{(i)}$ = 5.0 for (i=1, 2, …, M) at room temperature for a typical low carbon steel [7,23]. At higher temperatures, the value of $x^{(i)}$ decreases. Hence, at temperatures less than 400°C, the room temperature value was assumed and at temperatures greater than 400°C, x'1' was allowed to linearly decrease to a value of zero at 800°C. While the choice of this constant has implications in the current analysis, its impact will be most pronounced when the model is cycled to allow ratcheting or cyclic stress relaxation.

7.2. Target text

2000-01-0782

Ispitivanje višeosne termomehaničke deformacije primjenom neobjedinjenog modela plastičnosti

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SAŽETAK

Sposobnost modeliranja neelastične deformacije predstavlja praktičan interes u mnogim projektnim primjenama, posebno s trenutno sve češćom primjenom lakših struktura i komponenti koje rade na višim temperaturama. Termomehanička deformacija predstavlja nekoliko izazova jer se svojstva materijala mijenjaju s temperaturom, a na višim temperaturama vremenski ovisni fenomeni poput puzanja i/ili smanjenja naprezanja aktivni su mehanizmi deformacije. Zbog nedavnog uspješnog modeliranja mnogih plastičnih deformacija neovisnih o vremenu koriste se nedavne modifikacije Armstrong-Frederickovog tipa modela plastičnosti kao osnova za trenutni model. Izbor implementacije neobjedinjenog modela temelji se na ideji da različiti ili mehanizmi neovisni jedan o drugom upravljaju vremenski ovisnim i neovisnim plastičnim deformacijama. Iz literature također proizlazi sličan scenarij kod akumulacije štete. Nadalje, bilo je poželjno održati tenzorsku prirodu i vremenski neovisnog i „puzajućeg" ponašanja naprezanja i rezultata naprezanja, posebno za složenija višeosna termomehanička opterećenja poput onih na koja se može naići pri analizi zaostalih naprezanja koja proizlaze iz zavarivanja. Sherby-Dornov odnos snage i naprezanja puzanja koristi se za modeliranje vremenski ovisne deformacije sa zasebnom netranslativnom granicom razvlačenja puzanja. Koriste se jednoosni izotermni eksperimenti kako bi se prilagodile konstante modeliranja. Analizira se jednoosna, torzijska i osno-torzijska termomehanička opterećenja uz tri uvjeta ograničenja. Ispituju se dodatni testovi izotermne relaksacije kako bi se potvrdili osnovni koncepti modela. Opažena je inhibicija predvidive sposobnosti pri nekim temperaturnim uvjetima izostavljanjem odgovarajućeg primarnog modela puzanja, ali ukupne kvalitativne mogućnosti modela u skladu su s eksperimentalnim rezultatima.

UVOD

Mnoge inženjerske komponente podvrgnute su tijekom svog rada cikličkim toplinskim i mehaničkim opterećenjima za koje se smatra da spadaju pod općim nazivom termomehaničkog opterećenja. Čak i kod ponašanja neosjetljivog na brzinu većina materijala pokazuje temperaturnu ovisnost čak i za osnovna svojstva kao što su linearni modul elastičnosti i snaga razvlačenja. Pri razinama opterećenja većim od snage razvlačenja većina legiranih metala pokazuje neosjetljivost na brzinu na sobnoj temperaturi. Ova eksperimentalna promatranja bila su osnova za razvoj mnogih algoritama plastičnosti neovisnih o brzini. Autori su prepoznali Armstrong-Frederickov [1] model, koji koristi modifikacije koje su predložili Chaboche i dr. [2, 3], a dodatno poboljšali Ohno i dr. [4] i Jiang [5], kao prikladnu osnovu za modeliranje plastične deformacije neovisne o brzini [6, 7].

Na povišenim temperaturama moguće je da ponašanje ovisno o vremenu ili brzini dominira deformacijom. Tipična izotermna eksperimentalna promatranja za cikličku deformaciju su promjene u snazi razvlačenja i različito ponašanje otvrdnuća rezultata naprezanja nakon što se uzorak razvukao. Točna definicija povišene temperature može varirati za različite sustave legura, ali njezin početak bit će otprilike od trećine do polovice temperature taljenja u K. Čak i kod stacionarnog izotermnog puzanja karte mehanizma deformacije koje su predložili Ashby i dr. [8, 9] ilustriraju neke od složenosti uključenih u definiciju vremenski ovisne deformacije.

Mnogi prethodni istraživači [10 – 16] uspješno su koristili objedinjene teorije za modeliranje termomehaničke deformacije. Objedinjeni modeli često uzimaju u obzir dominaciju ili mehaničke ili vremenski ovisne plastične deformacije kada formuliraju varijable stanja. Općenito je rezultat plastičnog naprezanja rezultat ovih izračuna bez razlike između doprinosa ovisnih i neovisnih o brzini. Možda bi trebalo napomenuti da je Coffin [17] za eksperimente s povišenom temperaturom prvotno koristio rezultat plastičnog naprezanja kako se trenutno utjelovljuje u literaturi o zamoru. Halford, Manson i dr. [18, 19] razvili su tehniku raspodjele raspona rezultata naprezanja za procjenu oštećenja kada je uzorak podvrgnut i cikličnim preokretima i vremenima zadržavanja puzanja. Uočili su da se cikličko oštećenje ne može okarakterizirati samo rezultatom plastičnog naprezanja. Iako je proširenje podjele raspona rezultata naprezanja ili bilo koje druge tehnike procjene oštećenja izvan opsega ovog rada, ispitivanje odvajanja varijabli unutar opće kategorije rezultata plastičnog naprezanja za modeliranje deformacije bit će fokus sljedećeg prikaza. U ovom preliminarnom istraživanju razmotrit će se rezultati mehaničkog i stacionarnog plastičnog naprezanja puzanja, koje je mehanizam koji pokreće difuzija, uslijed dislokacijskog puzanja. Nadalje, tenzorska priroda rezultata naprezanja održat će se kako bi metoda mogla jednostavnije razmotriti opća višeosna stanja odnosa naprezanje – rezultat naprezanja.

MATERIJALI I TESTNA OPREMA

Materijal za sve eksperimente bio je vruće valjani niskolegirani niskougljični čelik sa udjelima mase legirajućih elemenata od: C 0,16 %, Mn 1,21 %, P 0,024 %, S 0,008 %, Si 0,19 %, Ni 0,02 %, Cr 0,01 %, Al 0,039 %, V 0,07 %. Uobičajeno se ovaj čelik primijenjuje kao osnovni metal u mnogim zavarenim konstrukcijama. Jednoosni i dvoosni ispitni uzorci izrađeni su od palete ploča debele 2,5 cm (1 inch) s uzdužnim smjerom podudarnim sa smjerom valjanja. Jednoosni uzorci bili su primjerci gumbaste glave duljine 15 mm i promjera 8 mm. Dvoosni uzorci bili su cjevasti primjerci duljine 30 mm, vanjskog promjera od 18 mm i unutarnjeg promjera od 12,7 mm. Mikrostrukturno ispitivanje ispitnih uzoraka otkrilo je trakastu mikrostrukturu koja se nalazi u mnogim valjanim čelicima. Mikrografske snimke poprečnih i uzdužnih presjeka ispitnih uzoraka otkrile su slično orijentirane slojeve ferita i perlita. Pretpostavka da bi se slično ponašanje materijala moglo vidjeti u poprečnom i uzdužnom smjeru je stoga razumna. Koristit će se ispitivanje aksijalnih i torzijskih mehaničkih svojstava da bi se potkrijepilo ovo opažanje.

Jednoosno ispitivanje provedeno je korištenjem servohidrauličkog teretnog okvira kapaciteta 100 kN s računalnim upravljačkim sustavom zatvorene petlje. Prikupljanjem podataka upravljalo je 32-bitno sučelje za prikupljanje podataka i signal između računala i teretnog okvira. Za mjerenje rezultata naprezanja korišten je visokotemperaturni ekstenzometar mjerne duljine 12,7 mm s izlazom pune skale ± 5 %. Šipke ekstenzometra brušene su kvarcom u šiljak koji odgovarao malim udubinama na bočnoj strani ispitnog uzorka. Izotermna kontrola temperature postignuta je upotrebom keramičke peći toplinskog zračenja od 2,5 kW s regulatorom temperature PID petlje. Termoparovi tipa K korišteni su za mjerenje temperature u tri intervala duž mjerne duljine ispitnog uzorka. Jedan termopar korišten je za kontrolu, a drugi za praćenje varijacija temperature duž ispitnog uzorka. Varijacije temperature duž duljine mjerača održavale su se unutar raspona od ± 5 °C. Za jednoosno termomehaničko ispitivanje radijacijska peć zamijenjena je indukcijskim grijačem od 5 kW koji radi na približno 250 kHz. Korištena indukcijska zavojnica dizajnirana je tako da je temperaturna varijacija duž uzorka bila unutar raspona od ± 5 °C. Više termoparova postavljeno je na različitim mjestima unutar mjerača kako bi se to ograničenje varijacije potvrdilo.

Za dvoosna ispitivanja korišten je servohidraulički tlačno-torzijski nosivi okvir s osnom nosivošću od 445 kN i torzijskom nosivošću od 5500 N m. Za kontrolu i prikupljanje podataka korišten je upravljački sustav zatvorene petlje sličan onom korištenom za jednoosna ispitivanja. Dvoosni su se rezultati naprezanja mjerili visokotemperaturnim ekstenzometrom duljine 25,4 mm koji može mjeriti rezultate osnog i torzijskog naprezanja. Izlaz pune skale za ekstenzometar bio je ± 5 % u rezultatima i osnog i torzijskog naprezanja. Za zagrijavanje svih cjevastih primjeraka korišten je indukcijski grijač. Termoparovi tipa K u kombinaciji s regulatorom temperature PID petlje korišteni su i za ove primjerke za nadzor i regulaciju temperature. Korišten je postupak projektiranja zavojnice sličan onom koji se koristi za jednoosne termomehaničke eksperimente.

Osni termomehanički eksperimenti provedeni su s obzirom na tri slučaja ograničenja rezultata osnog naprezanja: potpuno ograničeno, djelomično ograničeno i pretjerano ograničeno. Za svaki uzorak izmjeren je koeficijent toplinske ekspanzije bilježenjem neograničene toplinske deformacije povezane s poznatom temperaturnom promjenom i izvođenjem linearne regresije dobivenih podataka. Temperaturni su rasponi bili ograničeni od 100 do 400 °C i 100 do 600 °C uz korištenje brzina grijanja i hlađenja od 100 °C po minuti za sva ispitivanja. Donja temperaturna granica od 100 °C odabrana je na temelju činjenice da je hlađenje zrakom onemogućilo postizanje temperatura ispod 100 °C za gore navedene brzine hlađenja. Ukupni maksimalni raspon rezultata osnog naprezanja na uzorku bio bi 50 % manji ili veći od maksimalnog raspona rezultata toplinskog naprezanja tijekom ciklusa za djelomično ograničene i pretjerano ograničene slučajeve. Za torzijska termomehanička ispitivanja učinkovito nestaju osno razmatrana ograničenja zbog odsutnosti učinaka toplinskog širenja na torzijske deformacije, što stvara situaciju bez ograničenja. Međutim, torzijski mehanički odgovor moguće je promatrati unutar ograničenog toplinskog ciklusa nametanjem lažnih osnih ograničenja, gdje su ulazi rezultata torzijskog naprezanja von Misesovi ekvivalenti rezultata osnog toplinskog naprezanja povezanog s nekom temperaturnom promjenom i uvjetom ograničenja. Za čisto torzijska termomehanička ispitivanja granice rezultata naprezanja smatraju se von Misesovim ekvivalentima za odgovarajuće prošle rezultate jednoosnog naprezanja. Istraživalo se temperaturne raspone i brzine zagrijavanja ili hlađenja slične onima koji su razmatrani u osnim termomehaničkim eksperimentima. Svi testovi provedeni su neusklađenim ciklusima rezultata toplinskog i mehaničkog naprezanja.

ANALITIČKO MODELIRANJE I OSNOVNI EKSPERIMENTI: MEHANIČKA DEFORMACIJA

Zbog raznolikosti provedenih eksperimenata vjerojatno je manje zbunjujuće uvoditi ih sa svakim novim razvojem teorije. Za izotermalnu analizu neovisnu o brzini uobičajeno je dekomponirati rezultate naprezanja na elastične i plastične komponente koje se dalje nazivaju rezultatima mehaničkog naprezanja. Dodavanje temperaturnih varijacija obično dovodi do razmatranja rezultata toplinskog naprezanja uzrokovanog koeficijentom toplinskog širenja sažetim u izrazu prikazanom ispod.

$$\varepsilon_{kl} = \varepsilon_{kl}^{\Delta T} + \varepsilon_{kl}^{E} + \varepsilon_{kl}^{P} \tag{1}$$

Indeksi ΔT, E i P predstavljaju rezultate toplinskog, elastičnog i plastičnog naprezanja. Rezultati naprezanja ovisni o vremenu često su u objedinjenim teorijama uključeni u isti pojam kao rezultati mehaničkog plastičnog naprezanja. Moguće je dodatno podijeliti rezultate naprezanja korištenjem sljedeće formule:

$$\varepsilon_{kl} = \varepsilon_{kl}^{\Delta T} + \varepsilon_{kl}^{E} + \varepsilon_{kl}^{MP} + \varepsilon_{kl}^{CP} \tag{2}$$

Iako se nomenklatura četvrtog člana može rastaviti na primarne, sekundarne i druge komponente puzanja, budući da će se u sljedećoj analizi razmatrati samo stacionarno puzanje zbog penjanja dislokacije, samo je jedan član prikazan u ovoj jednadžbi. Općenito se metodologiju ne ograničava na ovu dekompoziciju. Algoritam mehaničke plastičnosti [6, 7] zahtijeva inkrementalno rješenje. Zbog promjena temperature promijenit će se čak i linearna elastična svojstva, stoga će se formulirati inkrementalno rješenje za jednadžbu 2.

TOPLINSKA DEFORMACIJA – najshvatljiviji izraz je rezultat toplinskog naprezanja gdje je korištena sljedeća jednadžba:

$$d\varepsilon_{kl}^{\Delta T} = \alpha\, dT\delta_{kl} + T\left(\frac{d\alpha}{dT}\right) dT\delta_{kl} \tag{3}$$

dT je promjena temperature, α je koeficijent toplinskog širenja, a δ_{ij} je Kroneckerova delta. Kroneckerova delta omogućuje pojavu izotropnih volumetrijskih rezultata toplinskog naprezanja. Za eksperimentalne temperature u rasponu od 20 do 700 °C ne očekuju se fazne promjene za ispitivani niskougljični čelik, a pretpostavka da je α konstanta eksperimentalno je potvrđena. Stoga se zanemaruje drugi član desno u jednadžbi (3). Ako je koeficijent toplinskog širenja ovisan o temperaturi, tada bi oba člana mogla biti važna. Važnost člana također može ovisiti o korištenoj tehnici rješenja. Treba napomenuti da se ova α razlikuje od sličnog simbola s indeksima koji se koriste za predstavljanje člana dugotrajnog unutarnjeg naprezanja u algoritmu kinematičkog otvrdnjavanja.

ELASTIČNA MEHANIČKA DEFORMACIJA – Mehanička elastična deformacija se inkrementalno modelira pretpostavkom homogenog izotropnog linearnog odnosa Hookeovog zakona prikazanog ispod.

$$\varepsilon_{kl}^{E} = \left(\frac{\sigma_{kl}}{2G}\right) - \left(\frac{v\sigma_{jj}}{E}\right)\delta_{kl} \tag{4}$$

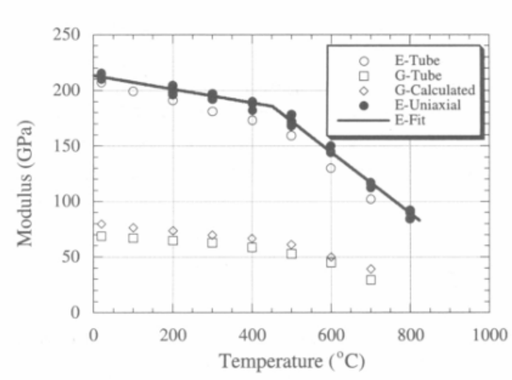
E je modul elastičnosti, *v* Poissonov omjer, a G modul posmika. Očekuje se da će se oba modula mijenjati s temperaturom i trenutno pretpostavljamo da je Poissonov omjer konstanta. Diferencijacija daje sljedeću inkrementalnu formulu za elastičnu deformaciju:

$$d\varepsilon_{kl}^{E} = \left(\frac{d\sigma_{kl}}{2G}\right) + \left(\frac{-\sigma_{kl}}{2G^2}\right)\left(\frac{dG}{dT}\right)dT - \left(\frac{vd\sigma_{jj}}{E}\right)\delta_{kl} - \left(\frac{-v\sigma_{jj}}{E^2}\right)\left(\frac{dE}{dT}\right)dT\delta_{kl} - \left(\frac{\sigma_{jj}}{E}\right)\left(\frac{dv}{dT}\right)dT\delta_{kl} \tag{5}$$

Drugi, četvrti i peti član rezultat su razlikovanja i razmatranja linearno elastičnih svojstava materijala kao funkcije temperature. Općenito su linearni modul i modul posmika povezani sljedećom jednadžbom:

$$G = \left(\frac{E}{2(1+v)}\right) \tag{6}$$

Potpuno obrnuta izotermna jednoosna te isključivo torzijska ispitivanja upravljana naprezanjem provedena su na temperaturama od 20, 200, 300, 400, 500, 600 i 700 °C za određivanje E i G. Razine naprezanja odabrane na danoj temperaturi bile su približno trećina do polovice od očekivanog pomaka snage razvlačenja od 0,2 %. Slika 1 prikazuje temperaturnu varijaciju ovih dviju konstanti i modul posmika izračunat uz pretpostavljen elastični Poissonov omjer v = 0,3. Čini se da je pretpostavka Poissonovog omjera neovisnog o temperaturi razumna. Ovo opažanje eliminira peti član u jednadžbi (5).



Slika 1: Prikaz linearnih elastičnih značajki materijala ovisnih o temperaturi

Jednostavni dvolinijski prikaz (Dodatak I) osnog modula E u odnosu na temperaturu smatra se dovoljnim za modeliranje linearnih elastičnih svojstava. Ovo uklapanje nije kontinuirano u odnosu na prvu derivaciju. Ovo se može činiti problematičnim s obzirom na drugi i četvrti član jednadžbe (5). Međutim, ako se odabere dovoljno mali vremenski prirast, zaključno je da se oni mogu zanemariti u sljedećoj analizi. U osnovi se izostavljanjem drugog i četvrtog člana svaki vremenski korak u rješenju smatra izotermnim događajem. Ovo je razumna pretpostavka zbog odabranih malih brzina zagrijavanja i hlađenja. Brže zagrijavanje i hlađenje bi u nekom trenutku rezultiralo temperaturnim gradijentima u radijalnom smjeru uzorka koji također nisu uzeti u obzir u ovoj analizi.

PLASTIČNA MEHANIČKA DEFORMACIJA - Bez razmatranja prednosti različitih modela plastičnosti neovisnih o brzini autori su odlučili implementirati inkrementalni format temeljen na Armstrong-Frederickovoj [1] hipotezi. Algoritam će specificirati (i) smjer i (ii) veličinu translacije granice razvlačenja i koristiti uvjet konzistencije za određivanje modula otvrdnjavanja. Zbog razlaganja rezultata mehaničkog naprezanja na elastičnu i plastičnu komponentu potrebno je razgraničiti ove dvije vrste deformacija. Obično se koristi funkcija razvlačenja kao što je prikazano u sljedećoj jednadžbi:

$$f = (S_{kl} - \alpha_{kl}) : (S_{kl} - \alpha_{kl}) - 2k_M^2 = 0 \quad (7)$$

s izračunom S_{kl}:

$$S_{kl} = \sigma_{kl} - \frac{\sigma_{jj}}{3} \delta_{kl} \quad (7a)$$

k_M je naprezanje razvlačenja pri jednostavnom posmiku, S_{kl} je tenzor devijatorskog naprezanja, a α_{kl} je tenzor dugotrajnog unutarnjeg naprezanja. Za potrebe ovog istraživanja k_M je konstanta na danoj temperaturi, što implicira da se razmatra samo kinematičko otvrdnjavanje. Bez gubitka općenitosti koristi se uvjet toka normalnosti [20].

$$d\varepsilon_{kl}^P = \frac{1}{h} \langle dS_{mn} : n_{mn} - \sqrt{2} \frac{dk_M}{dT} dT \rangle n_{kl} \quad (8)$$

Prefiks d označava infinitezimalni prirast diferencijacije. Veličine ε_{kl}^P i σ_{kl} predstavljaju redom tenzor rezultata plastičnog naprezanja i tenzor naprezanja, a n_{kl} označava jediničnu normalu na granici razvlačenja i definira se sljedećom formulom:

$$n_{kl} = \frac{S_{kl} - \alpha_{kl}}{|S_{mn} - \alpha_{mn}|} \text{ (bez zbrajanja preko k, l)} \quad (9)$$

Razdjelnik između dva tenzora označava njihov unutarnji količnik. Simbol <> označava MacCauleyevu zagradu (tj. <x> = 0,5 (x+|x|)), a h je skalarna funkcija koja se često naziva funkcijom modula plastičnosti. Drugi član unutar zagrada u jednadžbi (8) ponovno odražava promjenu brzinski neovisne snage razvlačenja s temperaturom. Ovaj izraz zanemarit će se u trenutnoj numeričkoj simulaciji. Količina dp općenito se naziva ekvivalentni prirast rezultata plastičnog naprezanja i definira se sljedećom formulom:

$$dp = \sqrt{d\varepsilon_{kl}^P : \varepsilon_{kl}^P} \quad (10)$$

Veliki doprinos modifikaciji Armstrong-Frederickove relacije otvrdnjavanja dali su Chaboche et al. [2, 3]. Predložili su da se ukupno dugotrajno unutarnje naprezanje sastoji od niza aditivnih dijelova pri čemu svaki dio dugotrajnog unutarnjeg naprezanja slijedi Armstrong-Frederickovu formulu prikazanu ispod.

$$\alpha_{kl} = \sum_{i=l}^{M} \alpha_{kl}^{(i)} \quad (11)$$

Indeks u zagradama (i) općenito se odnosi na broj članova u ekspanziji dugotrajnog unutarnjeg naprezanja M. Naknadna poboljšanja modela Ohnoa i Wanga [4] i Jianga [5] rezultirala su sljedećom formulom za povećanje svakog dijela dugotrajnog unutarnjeg naprezanja:

$$d\alpha_{kl}^{(i)} = c^{(i)} r^{(i)} \left(n_{kl} - \left(\frac{\left|\alpha_e^{(i)}\right|}{r^{(i)}} \right)^{x^{(1)}+1} L_{kl}^{(i)} \right) dp + c^{(i)} \left(n_{kl} + \left(x^{(i)} + 1\right) \left(\frac{\left|\alpha_e^{(i)}\right|}{r^{(i)}} \right)^{x^{(1)}+1} L_{kl}^{(i)} \right) \frac{dr^{(i)}}{dT} dT$$

(12)

Sljedeća nomenklatura je također korisna:

$$L_{kl}^{(i)} = \frac{\alpha_{kl}^{(i)}}{\left|\alpha_e^{(i)}\right|} \text{ (bez zbrajanja preko k, l)}$$

i

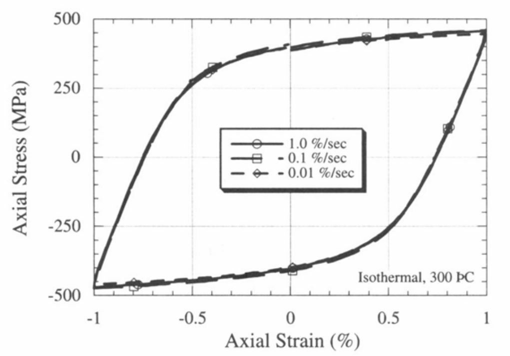
$$\left|\alpha_e^{(i)}\right| = \sqrt{\alpha_{mn}^{(i)} : \alpha_{mn}^{(i)}} \text{ (bez zbrajanja preko i)} \quad (13)$$

Kad je $x^{(i)}$ = 0, prvi redak (tj. izraz dp) jednadžbe (12) identičan je Chabocheovom izvornom izotermnom modelu neovisnom o brzini. Drugi član, doduše proizvoljan, rezultat je dopuštanja da samo $r^{(i)}$ bude funkcija temperature. Daljnja rasprava o ovom izrazu slijedi kasnije. U kontekstu ovog rada, razmatrana svojstva materijala predstavljat će ciklički stabilan odgovor, a materijal će se smatrati homogenim izotropnim tipom Masing, stoga je dk = 0 pri konstantnoj temperaturi.

Istražene su implikacije jednadžbi tipa ovisnog o amplitudi koji nije prema Masingovom modelu za deformaciju neovisnu o brzini [21]. Jedna od značajnih karakteristika ovog modela je da dio dugotrajnog unutarnjeg naprezanja nikada neće izaći izvan površine koja ima radijus $r^{(i)}$ i koja je centrirana u ishodištu. Osim toga, površina se ne smije okretati. Ova površina će se nazivati graničnom površinom za dio dugotrajnog unutarnjeg naprezanja. Bitno je naglasiti da se granična površina u trenutnom kontekstu ne smije poistovjetiti s drugim referencama na granične površine kao što su one koje se koriste za model dviju površina. Za daljnju raspravu vidi Jiang i Kurath [7]. Uvjet konzistencije zahtijeva da tijekom elastično-plastične deformacije stanje naprezanja ostane na granici razvlačenja. U kombinaciji s jednadžbama (7) i (8) uvjet konzistencije rezultira sljedećim izrazom za funkciju modula plastičnosti:

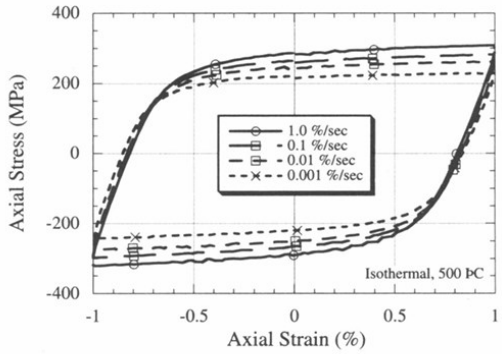
$$h = \sum_{i=l}^{M} c^{(i)} r^{(i)} \left(1 - \left(\frac{\left|\alpha_e^{(i)}\right|}{r^{(i)}} \right)^{x^{(i)}+1} L_{kl}^{(i)} : n_{kl} \right) \quad (14)$$

Kako bi se okarakterizirao osnovni odgovor ispitivanog materijala, inkrementalni postupni testovi kontrolirani rezultatom jednoosnog naprezanja [22] provedeni su na temperaturama od 20, 200, 300, 400, 500, 600 i 700 °C uz korištenje potpuno obrnutih maksimalnih amplituda naprezanja od 1,0 %. Brzine naprezanja od 0,0001, 0,001, 0,01, 0,1 i 1,0% po sekundi ispitane su na svakoj temperaturi. Reprezentativne vanjske petlje jednoosnih ispitivanja na 300, 500 i 700°C prikazane su na slikama 2 a – c. Korisno je napomenuti da korištenje inkrementalnih testova tjera materijal da reagira kao materijal tipa Masing. Iz ovih podataka inkrementalnih postupnih testova bilo je moguće odrediti pomak snage razvlačenja od 0,05 %. Ovaj se pomak često koristi u modeliranju plastičnosti i nije standardna metoda za određivanje pomaka snage razvlačenja za jednoosna vlačna ispitivanja. Rastuća polovica najudaljenije petlje inkrementalnog bloka koraka normalizirana je na ishodište koje odgovara nultom naprezanju i deformaciji. Amplitude su naprezanja i rezultata naprezanja u njihovoj krivulji prepolovljene, što učinkovito pretvara prvu polovicu petlje u pseudomonotonu krivulju grafa naprezanje – rezultat naprezanja.

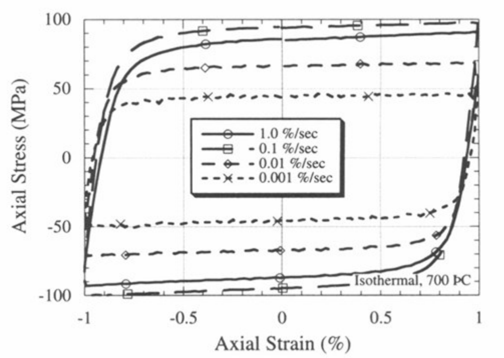


Slika 2a: Eksperimentalne vanjske petlje izotermnih inkrementalnih postupnih testova na 300°C

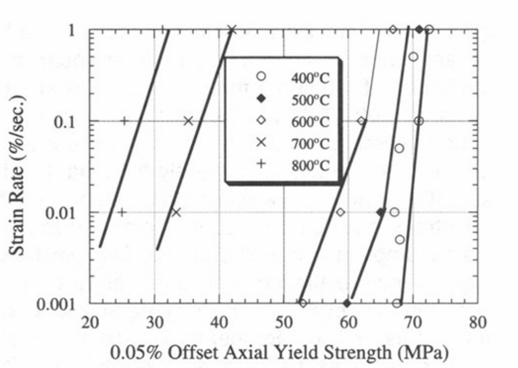
U ovom trenutku korisno je proslijediti definiciju koja se koristi za definiranje ovisnosti ili neovisnosti o eksperimentalnoj brzini. Slavic i Sehitoglu [10] koriste brzinu rezultata naprezanja u odnosu na pomak snage razvlačenja od 0,05 % kao što je prikazano za trenutni materijal na slici 3. Strmiji nagibi povezani su s ponašanjem neovisnim o brzini ili s dominacijom mehaničke plastičnosti, dok se za pliće nagibe smatra da ih kontroliraju vremenski ovisni fenomeni. Ispitivanja torzijskog inkrementalnog koraka s potpuno obrnutom amplitudom od 1,732 % inženjerskog rezultata posmičnog naprezanja provedena su na istim temperaturama i pri brzinama rezultata posmičnog naprezanja od 0,001732, 0,01732, 0,1732 i 1,732 % po sekundi kako bi se usporedila ovisnost o brzini posmika s onom opaženom u jednoosnim ispitivanjima. Pretpostavka da je 1,732 % rezultata posmičnog naprezanja ekvivalentno rezultatu jednoosnog naprezanja od 1,0 % za čisto torzijsko opterećenje upravljala je usporednom analizom. Ova pretpostavka temelji se na von Misesovom potpuno plastičnom odnosu ekvivalencije. Rezultati kvalitativno odražavaju one prikazane na slici 2. Općenito su umjereno brzo postignuti rezultati naprezanja i niske temperature u režimu ispitivanja kategorizirane kao neovisne o brzini. Više temperature i sporiji rezultati naprezanja pokazuju u suprotnom veću ovisnost o brzini. Općenito je proučavani materijal pokazao neovisnost o brzini na temperaturama ispod 350°C.



Slika 2b: Eksperimentalne vanjske petlje izotermnih inkrementalnih postupnih testova na 500°C

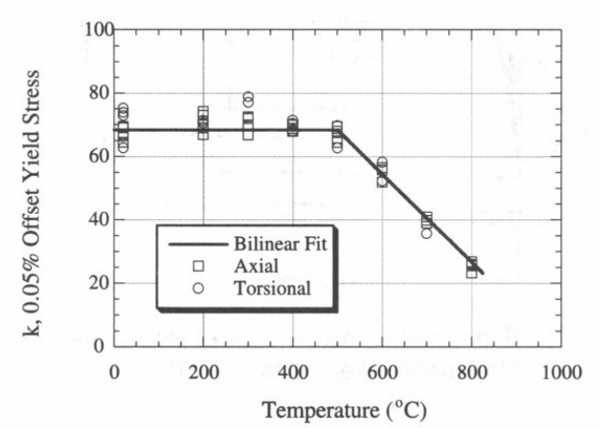


Slika 2c: Eksperimentalne vanjske petlje izotermnih inkrementalnih postupnih testova na 700°C

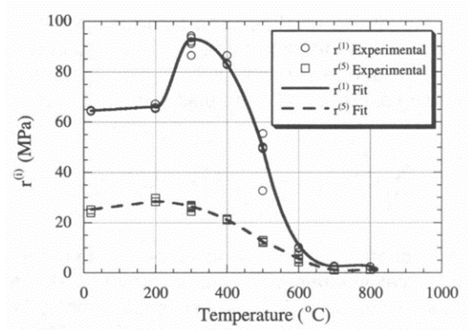


Slika 3: metodologija određivanja ovisnosti ili neovisnosti o brzini cikličnih testova.

Zbog odabrane dekompozicije rezultata plastičnog naprezanja bilo bi poželjno koristiti samo one testove za koje se smatra da su neovisni o brzini da bi odgovarali pomaku snage razvlačenja od 0,05 % i varijabli plastičnosti $r^{(i)}$ na danoj temperaturi. Pojedinosti prilagodbe parametara plastičnosti $c^{(i)}$ i $r^{(i)}$ povezane su u prethodnim publikacijama [7, 23]. Kako je pretpostavljeno u jednadžbi 12, članovi $c^{(i)}$, koji zapravo dijele krivulju naprezanje – rezultat naprezanja u smislu rezultata plastičnog naprezanja, uzeti su neovisno o temperaturi. Podaci neovisni o brzini (Slika 3) korišteni su na temperaturama nižim od 550 °C. Na temperaturama višim od 550 °C nisu se mogli provesti istinski brzinski neovisni testovi zbog eksperimentalnih ograničenja, a podaci o najvišoj brzini rezultata naprezanja korišteni su za aproksimaciju ponašanja neovisnog o brzini. Slika 4 sažima varijablu plastičnosti k (jednadžba $k = \sigma_y/\sqrt{3} = t_y$) utvrđenu i jednoosnim ispitivanjem i samo torzijskim ispitivanjem. Dvolinijsko uklapanje smatra se dovoljnim i navedeno je u Dodatku 1. Ponovno će diskontinuitet derivacija na sjecištu dviju prilagodbi ograničiti razmatranje člana dT derivacije u jednadžbi (8). Povećanje ove konstante je na približno 300 °C, što se pripisuje starenju rezultata naprezanja koje će se zanemariti u ovoj analizi.



Slika 4: Temperaturno ovisni prikazi mehaničkog razvlačenja neovisnog o brzini.



Slika 5: temperaturno ovisan prikaz parametra otvrdnjavanja mehaničke plastičnosti, $r^{(i)}$

Ovisnost o temperaturi uzeta je u obzir pri određivanju $r^{(i)}$. Slika 5 ilustrira temperaturnu ovisnost dva $r^{(i)}$ člana. Učinci starenja rezultata naprezanja, kao što se očituje grbom na krivuljama $r^{(i)}$ između 200 i 400 °C, uključeni su u formulaciju ovog temperaturno ovisnog skalara. Njegov učinak je najzastupljeniji u krivulji $r^{(1)}$ i smanjuje se kako i raste kao što je prikazano na slici 5. Ostale krivulje općenito padaju redom kako je naznačeno gornjim prikazom. Niti jedna funkcija nije mogla prilagoditi varijable $r^{(i)}$ u cijelom temperaturnom rasponu, a korišteno je najbolje uklapanje u ograničenom rasponu temperatura. Funkcije i povezani temperaturni rasponi koji se koriste za uklapanje svih $r^{(i)}$ sažeti su u Dodatku 1. Smatralo se važnim gurati različita uklapanja kako bi se osigurao kontinuitet na temperaturi na kojoj funkcije mijenjaju oblik. Nije bilo nikakvih pokušaja da se osigura kontinuitet bilo koje od izvedenica u ovoj istrazi. Ohno-Wang [24, 25] i Chaboche [26] primijetili su slučajeve u kojima zanemarivanje dT člana u jednadžbi 12 može biti značajno. Oni proizvoljno odabiru sljedeći dT član koji će se dodati dp dijelu jednadžbe 12.

$$+\left(\frac{\alpha_{kl}^{(i)}}{r^{(i)}}\right)\frac{dr^{(i)}}{dT}dT \qquad (15)$$

Ako je $x^{(i)}$ = 0, njihov izbor nalikuje drugom članu dT dijela jednadžbe 12. Međutim, termička derivacija u jednadžbi 12 zanemarit će se. Autori tvrde da su se neke od poteškoća koje su primijetili prevladale poboljšanjima modela i korištenjem malog prirasta u tehnici rješenja.

U ovom trenutku formula za mehaničku deformaciju je gotova. Nedostatak stvarnih brzinski neovisnih podataka uzrokuje precijenjene parametre snage razvlačenja k i $r^{(i)}$ na temperaturama višim od 500 °C. O rezultirajućim ograničenjima slijedi rasprava u sljedećem odjeljku. Eksponent algoritma otvrdnjavanja, $x^{(i)}$ pokazao je vrijednost od približno $x^{(i)}$ = 5,0 za (i=1, 2, ..., M) na sobnoj temperaturi za tipični niskougljični čelik [7,23]. Pri višim temperaturama vrijednost $x^{(i)}$ opada. Stoga je na temperaturama nižim od 400°C pretpostavljena vrijednost sobne temperature, a na temperaturama višim od 400°C, $x^{(i)}$ se linearno smanjio na vrijednost nula na 800°C. Iako izbor ove konstante ima implikacije u trenutnoj analizi, njezin će utjecaj biti najizraženiji kada se model ciklički mijenja kako bi se omogućilo ubrzanje ili cikličko popuštanje naprezanja.