ENGLISH LANGUAGE EDITING

Spread of EDI from the Saudi Arabian SME Perspective

Studies on electronic data interchange (EDI) adoption in various developing countries are being performed and most of them are exploratory in nature. Several practitioners and researchers involved in these studies have recognized the importance of the high penetration levels for DEI success. However, for investigating such issues, four factors affecting EDI adoption into medium and small industries (SMEs) are identified. These factors include perceived benefits (PB), environmental influence (EI), organizational readiness (OR), and external pressure (EP). When the anticipated effects of all these factors are combined, an EDI adoption model can be developed for SMEs. This model's applicability was demonstrated empirically with the help of survey results by distributing questionnaires to nearly 269 out of 500 SMEs located in Saudi Arabia. Their responses were analyzed using the SPSS tool. All the abovementioned four factors were found to be significant in EDI adoption in SMEs; PBs were considerably more important compared to remaining three factors. To conclude, recommendations have been made for EDI adoption into SMEs in the future. It is specifically suggested that EDI initiators pursue promotional efforts with the intention to enhance the perceptions of EDI advantages for the business partners, thereby providing technological and financial help to partners with low OR and carefully select in addition to enacting influential strategies for reducing or even overcoming negative attitude.

Keywords: adoption, SMEs, EDI

1. Introduction

Similar to various interorganizational information systems (IS), electronic data interchange (EDI) has been theoretically discussed as a technology providing strategic advantages to individuals who are implementing such systems (Awni, 2013). However, although EDI offers well-known benefits, its increasing adoption primarily in small businesses has been slower as anticipated and it is much slower in larger organizations (Awni, 2013). In spite of its capability to replace costly and inefficient paper-based processes with computer-based communication processes, medium and small industries (SMEs) seem to be still reluctant in adopting such a technology. According to Awni's (2013) taxonomy of IS innovations, EDI is categorized as a Type III innovation. Swanson asserted that compared to the small organizations, larger organizations possess the capacity of processing information in higher volumes, interacting much

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frequently with the external environment, and having a greater variety of specialized jobs. All these factors justify the adoption of more frequent Type III innovations. On the other hand, small businesses are often characterized as firms with low IT sophistication levels, availability and underutilization of resources, and weak market positions in addition to lack of IT integration. Such constraints can cause these small businesses to avoid adoption of Type III innovations like EDI. The problem becomes a greater cause of concern as small businesses are the backbone of the economy of several countries. For instance, in USA, small businesses are creating 2 out of every 3 new jobs, thereby producing 39% of the gross national product, resulting in half or even more technological innovations in the country (Awni, 2013). Considering the importance of achieving a high penetration level for the success of EDI, it is therefore important to understand the major factors that affect EDI adoption into small businesses. In this study, this issue was addressed. From the theoretical perspective, this study also aimed to address the lack of general research and theories on IT adoption into SMEs for competitive purposes.

1.1 Research Questions

In this study, two vital issues are being addressed:

1) What are primary factors influencing the adoption and impact of EDI on small businesses?

2) How can the proponents of EDI systems assist in expediting its adoption process by their small partners?

1.2 Research Objectives

The objective of this study is as follows:

- Examining the factors related to EDI adoption including those that affect its adoption into SMEs in Saudi Arabia, and building an EDI adoption model for the SMEs of Saudi Arabia
- Examining factors that affect the adoption of EDI technology in SMEs in Saudi Arabia
- Proposing the EDI technology model that can be adopted by Saudi Arabian SMEs

For examining all these factors, research reviews of past empirical and conceptual research on the EDI adoption as well as its impact has formulated for EDI adoption by focusing on the small business framework as well as testing its validity with 7 case studies. Literature review summary, description of the EDI model that is adopted by small businesses, summary of empirical findings, overview of research methodologies, recommendation list for EDI initiators, and description of suggestions for research in future comprise this paper.

2. Literature Review

2.1 Electronic data interchange (EDI)

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Electronic data interchange is a cooperative interorganizational system allowing business and trading partners to exchange the structured business information between different computer applications via an electronic method (Swatman and Swatman, 1992). The IOSs are telecommunication-based computer systems that are used by two or more organizations for data sharing as well as sometimes sharing of applications among different organization users (Barrett and Konsynski, 1982; Cash, 1985). Pfeiffer (1992) states that for IOS to become classified as an EDI, it should possess particularly essential features. It should have a minimum of two organizations in a business relationship as the users. Tasks like data processing pertaining to transactions at all (both) organizations should be assisted by application systems that are independent. It is a property unique to EDI because other IOSs are single system-based applications that are utilized by several users. Data exchange integrity between the application systems of trading partners should be guaranteed by the concerning formatting rules and data coding agreements. Finally, Pfeiffer (1992) explains that the exchange of data between application systems should be accomplished through telecommunication links.

2.2 EDI Adoption

Most of the previous EDI studies have made use of diffusion of the innovations theory (Rogers, 1983) for identifying innovation (EDI systems) attributes influencing the adoption of EDI. Among the much commonly investigated EDI characteristics, the ones that promote EDI adoption are relative advantage (that is perceived advantages of EDI as well as the impact), trialability (such as prototypes, pilot tests, and so on), and compatibility (both organizational and technical). Perceived relative benefit of EDI is the one variable that is consistently been regarded as among the most vital adoption factors as well as the most vital factor for IT (information technology) growth in SMEs (Cragg and King, 1993). Therefore, perceived benefits of EDI were included in our framework one of the primary explanatory factors for EDI adoption.

Various factors inhibiting EDI adoption have been identified. Complexity and cost of technology are one among these factors. Others include necessity to change internal systems, lack of technological skills, and lack of system integration (Pfeiffer, 1992; Saunders and Clark, 1992). It expects inhibitors to play a bigger role in the context of those small organizations where IT sophistication and resources are limited (Swatman and Swatman, 1991). Empirical findings have therefore suggested that lack of technical skills and economic costs are the two most vital factors hindering the growth of IT in small organizations (Cragg and King, 1993). Hence, organizational readiness (OR) defined as the availability of organizational resources for EDI adoption is another factor in this study. Several factors clearly influence EDI adoption but as they have been generally identified by studying large organizations and hence their applicability is questionable in case of small businesses. Small organizations found to have varying technology adoption patterns compared to larger ones. Moreover, most of the previous studies have failed to recognize that EDI is a networked interorganizational system wherein power of EDI initiator, interdependencies, as well as trust between partners turn critical issues.

Awni (2013) in 100 SMEs survey found that factors such as environmental factors that are of higher consideration by adopters as compared to by Nano adopters as well as subject to increased government pressure are considerable. Much pressure from the trading partners who are actually

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EDI initiators play a critical role in the adoption of EDI by SMEs (Swatman and Swatman, 1991; Hart and Saunders, 1994; Webster, 1994). Literature suggests that the decision of a firm to adopt EDI is primarily based on what the business partners are doing instead of EDI characteristics (Bouchard, 1993). In fact, more than 70% of respondents in the latest surveys identified that customer mandate/pressure as the primary reasons for EDI adoption of 6. Therefore, the external pressure (EP) for adopting EDI is an additional factor in our study framework.

3. EDI adoption model for SMEs

In this research, the methods that were used were adopted from the EDI adoption model proposed by Izak Benbasat, Charalambos L Iacovou, Albert S Dexter (1995) and a model of understanding IT proposed by Afzaal H Seyal, Mohd. Noah Abd Rahman Hj. Four factors namely EP, environmental influence (EI), OR, and perceived benefits of EDI (PB) were identified as the primary reasons capable of explaining the adoption behavior of EDI into SMEs as well as expected effect of technology. The relationship between these factors and the EDI adoption process as well as their impact and integration are depicted in Figure 1.

3.1 Environmental Factors

Governmental policies as well as the effect of initiatives have been shown for stimulating information supply that can produce faster technology. For several organizations, the Saudi Arabia government has acted as the chief funding source for infrastructure. This study investigates the involvement and support of the government in EDI adoption into SMEs.

The Saudi Arabia government has shown its further commitment towards providing positive and legitimate leadership roles in the development of infrastructure for digitizing its economy.

In the recent years, several researchers have studied the role of the government. Awni (2013) found that the government's direct intervention can be regarded vital for the promotion of technological innovation, although the extent of influence on different firms can vary between countries.

Awni (2013) emphasized that private as well as government sectors play a vital role to support EDI framework pillars. An understanding of the governmental role as an EDI facilitator will assist in flourishing as well as maturing strategic framework for businesses that are Internet based. Awni (2013) examined the effect of government incentive programs on IT in 40 SMEs. Several evidences show that the incentive from the government in the form of financial, technological, and economical support facilitated simpler IT adoption. Goh (2014) suggested that the government can play a leadership role for diffusing innovation. Teo and Tan (2014) discussed the support and role of the government for adoption studies for Internet.

Awni (2013) made use of environmental aspects as vital factors for investigating the influence of these factors on EDI adoption. These findings suggest that the environmental aspect is a significant determinant of EDI adoption. Support from the government was quantified in the present study via a construct utilized by Tan and Toe (2014) for their study. Therefore based on this construct, the following hypothesis was proposed:

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H1: Government support is positively associated with EDI adoption.

3.2 Perceived EDI advantages

Several researchers and practitioners have attempted to identify the potential benefits offered by EDI technology. According to Pfeiffer (1992), the advantages are mostly operational savings associated with the internal efficiency of the organization as well as opportunities that are related to the effect of EDI on business relationships and processes. These are mostly competitive and tactical advantages.

Although the advantages of SMEs include huge financial savings, much attention has been given to the impact of EDI on business operations. Several opportunities are offered by EDI that could result in organizational benefits if they combine with re-engineering of business processes and appropriate business strategy (Swatman et al., 1993; Clark and Stoddard, 1994). This means that ideally EDI is best integrated with the core business of an organization as higher integration levels lead to increased expected advantages.

Perceived benefits of EDI refer to the extent of recognition of relative benefits offered by EDI technology to an organization. Increased managerial understanding of the relative benefits of EDI increases the likelihood of allocation of managerial, technological, and financial resources vital for implementing an integrated EDI system (Benbasat, el al., 1993). It is therefore anticipated that those SMEs whose management recognizes the advantages of EDI would be much likely to adopt EDI as well as enjoy increased advantages as compared to those whose management recognized PBs to a lesser extent.

H2: Perceived benefits perceived have a positive impact on the intention of EDI adoption.

3.3 Organizational Readiness for EDI

Basically, organizational readiness means the level of technological and financial resources of a firm. This factor was taken into consideration because of SMEs tending to lack resources that are vital for EDI as well as various other IT investments (Saunders and Clark, 1992; Bouchard 1993). Moreover, comparatively low computerization levels of operations of SMEs makes sophisticated information systems integration (like EDI) tough, necessitating expensive expenditures (that is technology, employees, and capital). As small organizations tend to lack these resources, their ability to capitalize all strategic advantages of any specific technology usually is limited.

Financial readiness basically refers to the financial resources available for implementing EDI for paying for installation charges, subsequent implementation of enhancements, and ongoing costs during usage (like usage fees, communication charges, etc.). Though the EDI adoption cost can be restricted to a few hundred dollars (to run EDI software on personal, independent, frontend computers), its integration cost may be approximately 10,000$ (Bouchard, 1993). As integration is required for the success of EDI investments, one could easily notice the importance of financial resources. Usually, SMEs with available financial resources would be better equipped

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for implementing integrated EDI systems. Firms that can consequently afford much integrated, costly EDI projects are much likely at enjoying increased advantages of using such systems.

The second dimension of OR is "technological readiness," which is concerned with the sophistication level of usage of IT and IT management in an organization. Usually, sophisticated firms are not much likely to be intimidated by technology. They possess superior view of corporate data as an integral part of the overall management of information as well as have access to the required technological resources (i.e., expertise, component project leader, and hardware) (Pare and Raymond, 1991). Therefore, such sophisticated firms expediting EDI adoption is expected. Furthermore, firms with extremely integrated computerized processes are better prepared for undertaking integrated EDI projects that increase the impact of technology as well as offer increased benefits. To summarize, it is anticipated that the SMEs having increased OR for EDI would be much likely to adopt EDI and enjoy its increased benefits as compared to firms having lower readiness levels.

H3: Organizational readiness (OR) has a positive impact on the intention for adopting EDI.

3.4 External Pressure for Adopting EDI

The external pressure for adopting EDI signifies influence from the organizational environment. Two primary external pressure (EP) factors to adopt sources: 1) compulsion by trading partners and 2) competitive pressure when car manufacturers in the US needed their suppliers to make use of EDI in their transactions with them. By competitive pressure, we mean EDI capability level of firm's industry and much importantly that of its competitors. Since more trading partners and competitors are becoming EDI capable, SMEs are more inclined towards adopting EDI so as to maintain competitive position of their own.

From trading partners, compulsion is expected to be one of the most vital factors for EDI adoption by SMEs. As weaker partners in the interorganizational relationships, SMEs are highly susceptible to pressure from their stronger partners (Saunders and Hart, 1993). These impositions are especially prevalent in case of EDI because of the nature of its network.

The pressure that is exerted by the trading partners is a function of two factors: the potential power of an imposing partner and its chosen strategy of influence (Provan, 1980). It is not surprising that requests from potent partners (such as those that consume larger portions of sales or those that are generating a larger portion of profits for small firms) for becoming EDI capable are expected to be much influential in the adoption decision in case of SMEs compared to similar requests from lesser potent partners.

A potent partner could pursue three varying strategies for asking a smaller partner for adopting EDI. In the first kind of strategy, "recommendations," larger firms make use of information for altering the general perceptions of their smaller trade partners regarding how their organizations may more effectively operate by using EDI. Contrastingly, the other two strategies need compliance from smaller firms. The other is "promises" including all tactics suggesting that larger firms would offer the smaller partner with a specified reward (such as discounts for EDI-transacted goods, usage, and adoption of subside, etc.) if it turns EDI capable. The last one is

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"threats," which, on the other hand, refer to the actions that convey the intentions of larger firms towards applying negative sanctions (such as discontinuance of partnership) should the smaller company fail to become EDI capable. These threats have been implemented by large department store chains and automobile manufacturers in the recent years (Brent, 1994).

Because of the importance of the external integration in the EDI network, you can expect smaller organizations being more vulnerable towards competitive pressures as well as are more likely to comply with the demands of their trading partners compared to larger firms (Pfeffer and Salancik, 1978). Hence it is expected that the SMEs experiencing pressure from their partners or from competitors would adopt EDI more frequently as compared to those that do not encounter this pressure. As already outlined in Table 2, OR and PB are both expected to influence the

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Geochemical Exploration for Gold and the association of As-Cu-Pb-Sn-Mo-Bi-W-Zn-Li in the Upper Proterozoic Granitoids of the Wadi Rumman Area, Southwest Jordan

Abstract

The geochemical studies were conducted in an area covering about 15 km^2 of the south side of the Wadi Rumman area, SW Jordan. The study area included a part of a basement of complex exposed rocks in southwestern Jordan. The complexes comprised igneous and metamorphic suites, mostly from the late Proterozoic age. A systematic geochemical sampling was conducted using rock and heavy mineral-panned concentrate of geochemical samples. Fifty rock samples were collected from the granitic rocks, simple pegmatite dyke, quartz veins and alteration zone, which covered the area. Next, 45 heavy mineral-panned concentrate samples were collected from the alluvium in the stream sediment within the catchment area, and the dray was sieved to less than 1 mm grain size. The geochemical samples were analyzed for their trace elements and gold by using Ione Conductive Coupled Plasma Emission Spectroscopy (ICP-AES) and the Atomic Absorption Spectrometer (AAS) at Natural Resources Authority (NRA) Labs. The results of the geochemical analysis indicated the presence of gold and heavy minerals in the study area, a result considered abnormal in the rock samples. A strong positive correlation was recorded of Au with As, Cu and W (r = 0.82, 0.7 and 1.0), as with Mo (r = 0.83), Cu with Pb (r = 0.83), Sn with Mo (r = 0.73), Mo with W (r = 0.97), Zn with W (r = 0.71), and Li with Bi (r = 0.7). These correlations revealed gold associated within the hydrothermal alteration, quartz veins and pegmatite dyke. Abnormal metals such as As and Bi were good path-finders to find Au. The HM samples showed low positive linear correlations among the concentrations of Au with As, Zn and Li, and negative linear correlations of Au with Pb, Sn, Bi and W. The combination of both rock and heavy mineral concentrate samples show four geochemical anomalous areas of gold and heavy minerals. The geochemical signatures of Au and As in the Wadi Rumman appear to be in the hydrothermal alteration, quartz veins and pegmatite dyke, respectively. Heavy mineral concentration sampling delineated the Au geochemical anomaly in area 1 specificities with the rock geochemical anomaly of area 1, and no negate Au was investigated in the study samples.

Keywords:

Geochemical Exploration, Granitoids, Rock and Heavy Mineral, Wadi Rumman, Jordan

1. Introduction

Geochemical prospecting for minerals includes any method of mineral exploration based on

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the systematic measurement of one or more chemical properties of the naturally occurring materials. The chemical property measured is most commonly the trace content of some element or group of elements. The reason for recording these measurements is to discover abnormal chemical patterns or geochemical anomalies, related to mineralization. Among the several geochemical prospecting methods used to discover the study area, the heavy minerals and rock geochemical exploration methods were selected and used in the study area, as they are the more effective methods suitable for this type of region. Heavy mineral geochemical samples of less than 1mm grain size were collected from the alluvium in the stream sediment, which were a useful method of verifying any decision made during the geochemical exploration for minerals, including the transport distance of the gold nuggets and ultimately regarding the origin of the element dispersion halo **[1].** The fine fraction method is usually used in geochemical exploration, because of the small grain size, which makes it possible to use a small sample weight and to some extent eliminate the reduction and secondary sub sampling errors. For exploration mineralogists, the key problems arise from the low concentration thresholds of gold anomalies and the small particle size **[1].** Rock geochemical samples used to collect the composite sample caver about 5 feet across in area. The objective of this study was to undertake a geochemical exploration for minerals in the plutonic rocks, which cover the area under study, in an attempt to identify the areas of geochemical anomalies for Au, As, Cu, Pb, Sn, Mo, Bi, W, Zn and Li. It was also done to identify the possible presence of the ore minerals in the target areas by using the rock and heavy mineral geochemical exploration methods.

2. Geological Setting

The basement rocks exposed in southwestern Jordan are subdivided into two broad lithostratigraphic complexes, the Aqaba and Araba [3]-[5]. These complexes comprise the igneous and metamorphic suites, mostly of the late Proterozoic age. These complexes are separated by a regional unconformity (peneplanation), represented by the Saramuj Conglomerate Formation **[6]-[7].** The Aqaba complex (800 to ~570 Ma) includes the metamorphic and intrusive calc-alkaline plutonic and metamorphic rocks. The Araba complex (625-600 Ma), on the other hand, consists of the Safi and Finan granitic suite, and Qirenifat and Ahaymir volcanic suites **[8].** The area under study is included within the Aqaba complex and the outcropping from the late Proterozoic calc alkaline granitoids the Rumman and Yutum suite, such as Ishaar granite, Qara granite and Rashidiyya Aplite granite, respectively. The granitites are cross-cut by numerous dykes of varying composition (from acidic to basic) and thin quartz veins and an alteration zone. The lower Paleozoic sedimentary rocks for the Ram Sandstone group include Salib Arkoze Sandstone and Umm Ishrin Sandstone which are unconformable and overlaid Proterozoic igneous rocks **[9]-[10].** The area under study is located at 35⁰ 15ʹ 727″ - 35 ⁰ 15ʹ 730″ E and 29⁰ 30ʹ 3271″- 29˚ 30ʹ 3275″ N covering about15 km^2. The geological units are described as follows:

The Qara granite unit contains medium- to coarse-grained, pink- to whitish-pink to light grayish-pink syenogranite to monzogranite. The mesocratic rocks include small mafic clots at the outcrop, highly weathered and cut by dense dykes of rhyolite and quartz veins. The main mineral composition includes quartz, alkali feldspar and biotite with traces of hornblende and phaneritic in texture, particularly along the margins of the zone in contact with the Ishaar unit. Ishaar granite is medium to coarse grained, phaneritic in texture, grey to greenish-grey, which varies according to the granodiorite. Mesocratic, small circular mafic clots with biotite and hornblende are common, cut by dykes of variable compositions of rhyolite, pegmatite and quartz vines. Quartz, alkali feldspar and biotite constitute the main mineral composition. Rashidiyya Aplite Granite is distinguished by fine grain size, micro granite, pink to whitish-pink colors, leucocratic and sugary with aplitic texture. Acidic dykes and thin quartz veins cut through this unit. Quartz alkali

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feldspar and biotite form the main mineral composition. Salib Arkosic Sandstone Formation, Early Cambrian in age, consists predominantly of yellow, pink, and purple-brown colors, with very coarse- to medium-grained, cross-bedded arkosic and subarkosic sandstone; pebbles to cobble conglomerates are also locally present. Rounded to sub-rounded pebbles of milky-white quartz and pink feldspar are also seen. Umm Ishrin Sandstone Formation includes the middle to late Cambrian age, with brown, red-brown to yellowish-pink and grey colors, of medium to coarse-grained quartz arenite, with rounded granules and quartz pebbles. There are thin beds of fine-grained sandstone and siltstone exhibiting lineation. Secondary ferruginous and manganese ferrous show color banding and oxides with a massive-weathering face and the typical large trough cross-bedding with pebbles, occasionally overturned for sets is common. Angular clastic siltstone in locally eroded channels is evident, close to the gradational upper boundary of the formation; **Fig. 1** shows the geological map of the area of study.

The geologic structures of the area under study are affected by the tectonic activity that occurred during the late Proterozoic to the early Cambrian for the extension of the Arabian–Nubian shield which plunges to south Jordan **[11]-[12].** The early Paleozoic rocks of the Aqaba and Araba complexes of the Precambrian basement are affected by the northwest striking faults and tension joints. The NN-SSW faults, parallel to the rift, extend south into Saudi Arabia, where normal faulting and sinistral strike-slip movements can be demonstrated [13]. Major faults within the Aqaba complex are oriented to the north-northeast (0-15°) trend, revealed by the extensive Wadi Rumman and Wadi Rum faults. The areas of study (Wadi Rumman) affected by these faults, have recorded 300-450 m westerly downthrows and 4-5 km sinistral lateral displacement **10]**. The principal and subsidiary joints are shown in the various study units, in the E-W, ENE-WSW, and in the NE-SW directions for the study of the granitoid units and the NW-SE, N-S and E-W trends in the direction shown for the Salib and Umm Ishrin formations.

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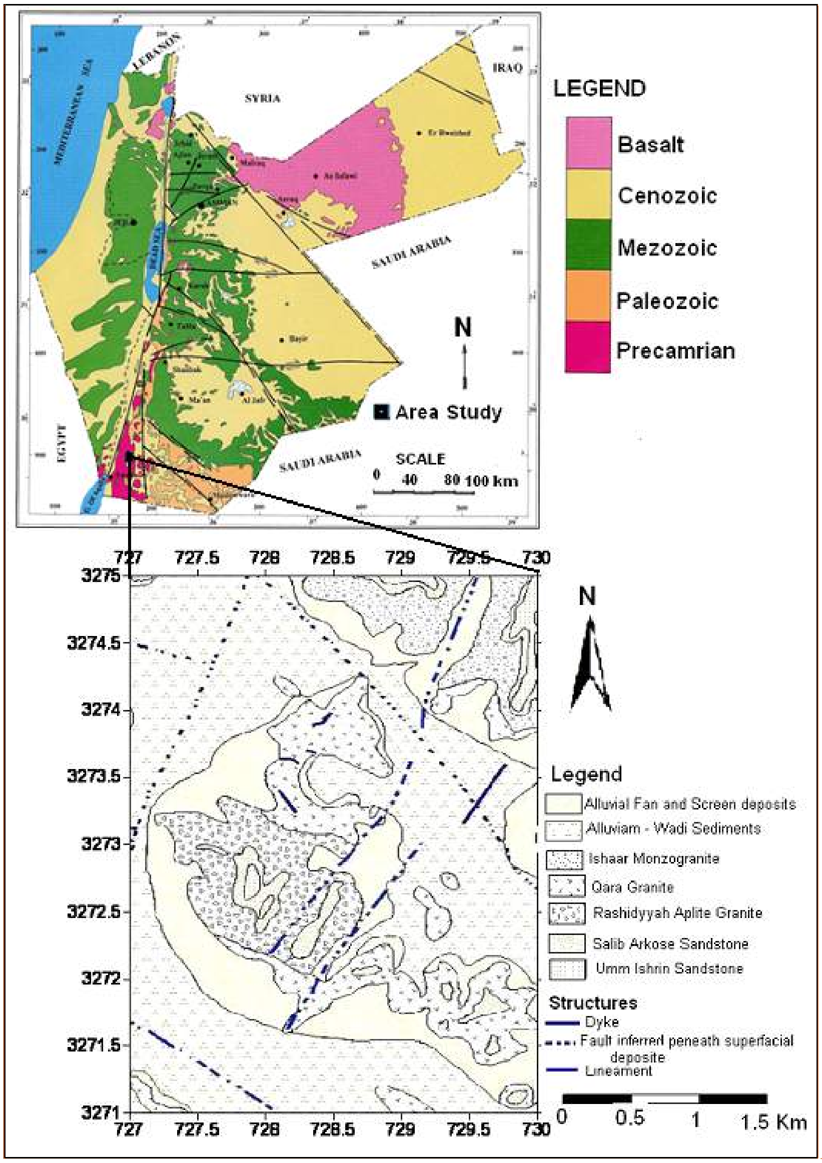

Fig. 1: Location and geological map of the area under study.

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3. Sampling and Analytical Techniques

Two geochemical methods of investigating rocks and heavy minerals were used in the geochemical exploration of the area under study. Sample points were selected from a published 1:50,000 scale topographic and geological map.

Fifty rock chip samples were collected from the outcropping of the granitic rocks, simple pegmatite, dyke, quartz veins and alteration zone, at a density of five samples per 1km^2 (**Fig. 2a**). The lithology, quartz veins and alteration intensity of the rocks were studied in the field under natural light using high magnification lenses. Thin sections were then prepared and detailed mineralogical and alteration features were studied under the petrographic microscope. The samples were crushed and powdered using a stainless steel Jaw Crusher and an Agate Ball Mill machine, to obtain grain size less than -63µ. The samples were quartered in order to get a statistically representative (splitter) fraction and powdered using two geochemical techniques at the Natural Resources Authority (NRA) labs.

Forty-five heavy mineral concentrated samples were collected from the alluvium in the stream sediment within the catchment area of the study, at a density of four samples per 1 Km^2 **(Fig. 2b)**. Then dry stainless steel sieving was performed at the sampling site to get about 4 L by volume of alluvium, of grain size less than 1mm. The samples were then placed in 8 L stainless-steel pans, and washed in sea-water close to Aqaba to eliminate material by the law of specific gravity and collect a resultant of about 200 g of heavy mineral concentrates. The concentrates were rinsed thoroughly in fresh water, placed on plates and sun dried.

3.1. Analytical Techniques

The trace elements were analyzed by decomposition using Ione Inductively Conductive Coupled Plasma Emission Spectroscopy (ICP-AES) at Natural Resources Authority Labs. A total of 1 g of the powdered (<80 mesh) sample mixed with 3 g of sodium peroxide (Na_2O_2) were placed in a zirconium crucible, and fused by heating it to 450°C for 45 mins, to obtain a sinter. Subsequently, 72 ml of deionized water was added to it and stirred for a few minutes; then 28 ml of diluted HCl in a ratio 1:1 was added to obtain clear solutions that were used to determine the trace element concentrations.

The Atomic Absorption Spectrometer (AAS), PerkinElmer 3030 Model was used for gold analysis in the Natural Resources Authority Labs. The analytical method consisted of dissolving the Au in the sample by heating with *aqua regia* solution (3 ml conc. HCl + 1 ml conc. HNO_3) plus iron. The gold (Au) was then extracted with methyl isobutyl ketone (MIBK) solution by introducing the organic phase into a pyrocoated graphite furnace and then analyzed for gold using the Atomic Absorption Spectrometer **[14].** The gold concentration was expressed in parts per billion (ppb). The lower detection limit of this analysis method was (10 parts per billion (ppb). Excel 2007 and Surfer 8 were used to perform statistical analyses of the data.

The mineral composition was identified using the petrographic microscope and X-ray Diffraction (XRD) by employing a Philips diffractometer with Cu Ka radiation, at the University of Al al-Bayt.

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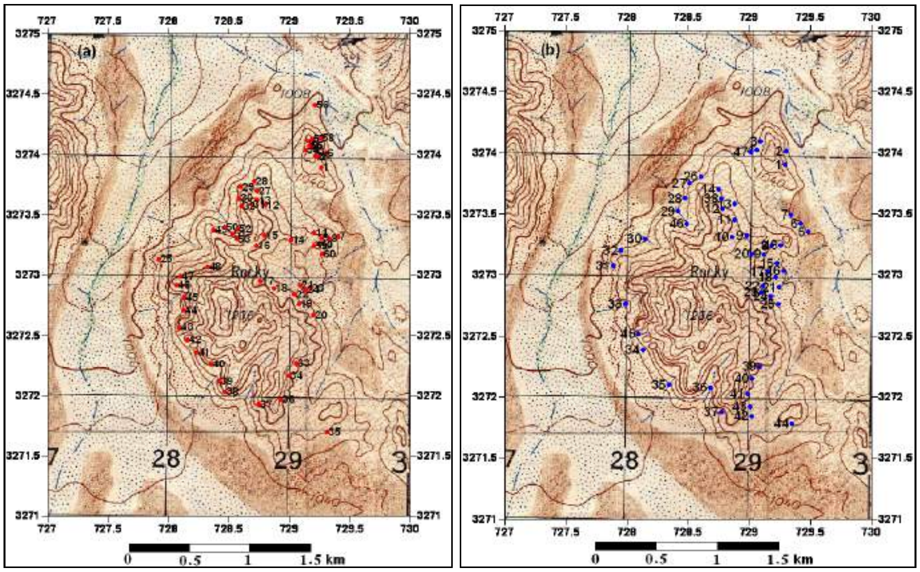

Fig. 3: (a) Rock sample location map, (b) Heavy mineral sample location map

4. Results and Discussion

4.1. Petrography and Mineralogy

The rock samples study showed leucocratic, holocrystalline and hypidiomorphic to allotriomorphic fine- to medium-sized grains, phaneritic to megaprophyritic in texture. Using the polarizer microscope and XRD, quartz, feldspar, biotite, hornblende and opaque minerals such as iron oxide and magnetite, were the main minerals identified. The secondary minerals included calcite, sericite, kaolinite and chlorite while the rare minerals found were wolframite (W), davite (B) and cassiterite (Sn). The common textures of the rock samples in the study were perthitic, poikilitic interstitial, zoning and polysynthetic twinning. The lithology and petrography of the area under study showed an alteration zone with high concentration of secondary and oxide minerals. These were indications of the mineralization ore minerals which were documented by chemical analysis for gold and the pathfinders for the geochemical association of the elements. The lithology and petrography are summarized in **Table 1**.

Table 1: Lithology and Petrography of the rock samples of the study.

Sample number	Lithology	Petrography
1, 2, 20	Aplite granite with ultration and highly crashed rocks	Granite rock fragments composed of quartz, feldspar, and biotite. Highly fractured crystals of feldspar, quartz, hornblende and epidote. Hornblende occurs in clots giving the rock a mottled appearance. The cemented material consists of calcite and very fine grains of quartz or cryptocrystalline. Quartz was partially metamorphosed to quartzite.
3, 26	Alteration granite, fine to medium grain size, mineral composition quartz, feldspar and biotite, with calcite veins associated in the alteration zone	Calcite minerals contain cavities filled with fibrous quartz and opaque minerals. Calcite shows polysynthetic twinning and two cleavage sets (rhomb cleavage). Silica occurs as cryptocrystalline fibrous chalcedony and fine-grains filled the fractures and spaces or voids. Micrographic textures are visible. Iron oxides occur surrounding the voids or separated along the fractures.
4, 6, 7, 8, 9, 10, 11,	The alteration zone includes quartz veins with	The major textures evident are equigranular, interstitial perthitic and poikilitic. Quartz occurs as anhedral and highly fractured crystals, filling up the spaces

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34, 60	highly crashed rocks	between the plagioclase crystals. Feldspar occurs as plagioclase, a major component and a few percent of perthite with perthitic texture. More than 40% is plagioclase found as euhedral and subhedral prisms showing zoning and polysynthetic twinning. It is highly weathered and altered to calcite and sericite. Biotite is rare and highly weathered having been altered to iron oxides.
12, 13, 14, 15, 16, 17, 18, 19, 23, 29, 30, 31, 33	Thin Quartz veins (2-5cm in thickness), showing a high degree of alteration and crashed rocks, and trace minerals, like Cu and Pb	The major texture is equigranular and spherulitic. It consists of euhedral elongated crystals of quartz and orthoclase as the major minerals due to the intergrowth between quartz and feldspar like a sheaf form. The slide shows cryptocrystalline silica as a banded rock from the veins, thin veins of cryptocrystalline and spherulitic chalcedony associated with sericite and calcite, fine-grained quartz and finally cryptocrystalline and fibrous chalcedony associated with sericite. A few crystals of orthoclase partially altered and sericite. Iron oxides occur as accessories as very fine aggregates.
21	Applite granite with green color and ultration	The slide shows felsitic rock composed of feldspar and quartz crystals. The feldspars are altered to sericite and kaolin minerals. Biotite occurs as rare mineral and is altered to chlorite.
22, 59	Quartz veins with the secondary green color of the minerals	Graphic texture is observed. The biotite xenocrysts are partially altered to chlorite and iron oxides. Iron oxides and black spots occur as accessories and separated randomly in the groundmass.
24, 32, 27, 28	Basaltic dyke cutting the granite host rocks, with quartz veins	This slide shows two types of rock composition, the first being andesite rock. It consists of feldspar and glass. The feldspar (plagioclase) occurs as small laths and shows twinning and zoning. It is predominantly trachytic in texture. It contains black materials which could be volcanic glass or opaque minerals. The second type comprises chalcedony veins cutting the andesite rock. Spherulitic texture is predominant in the dyke and consists of a dense mass of very intergrown quartz and alkali feldspar (orthoclase) needles, radiating from a common nucleus. These spherulites are followed by fine-grained quartz presenting a drusy structure followed by calcite mineral in the middle (forming bands). This dyke is rich in opaque and fine accumulated band-like aggregates separated from the beginning of the dyke to its end.
35	Granodiorite, composite of mafic minerals feldspar, Biotite and hornblende.	Granular, consertal and poikilitic textures predominate. Anhedral and highly fractured quartz crystals comprise about 30%. Feldspar includes both the orthoclase and plagioclase forms. Plagioclase constitutes more than 45% and occurs as euhedral to subhedral prisms showing zoning and polysynthetic twinning. It has been highly weathered and altered to clay and sericite. Biotite occurs in about 10% of highly weathered rock, altered to chlorite-like masses.
36	Granodiorite is a composite of mafic minerals feldspar, and Biotite, with a high degree of alteration	Granular texture; metamorphic rock fragments of the Biotite Schist consisting of quartz, feldspar and biotite. Biotite was partially altered to chlorite and iron oxides; opaque minerals were seen associated with biotite. Crystals (phenocrysts) partially altered to sericite or clay especially at the center. Feldspar crystals of fractured quartz are visible. All these rock fragments and xenoliths are cemented by fine-grained of quartz.
37, 5	Rhyolite dyke - fine to medium-sized grains of quartz and feldspar.	Equigranular and perthite texture is present. Quartz, perthite and orthoclase are the major minerals. Feldspars are altered to clay and biotite to sericite. Rare occurrences of altered muscovite. Opaque minerals as accessories occur as very fine aggregates.
38	Granite - fine to medium grains with highly crashed and withering composites of quartz and feldspar	Phenocrysts of zoned plagioclase are altered to kaolin. Cryptocrystalline silica dust is present as cemented material or as veins. Opaque minerals occur as accumulated aggregates.
39	Granite - fine to medium grains	The major textures are granular, consertal and poikilitic, consisting of quartz with anhedral crystals and the highly fractured forms constitute about 20%. In some places they occur as clots (fine–grained) between the coarse crystals. Biotite is altered to iron oxides.
40, 41	Simple Pegmatite dyke	The major textures include granular, consertal and poikilitic. It consists of quartz: it occurs as anhedral crystals and highly fractured crystals forming about 40%. Feldspar occurs as perthite and shows perthitic texture, is altered to clay forming more than 30%, while the plagioclase forms about 25%. It occurs as euhedral to subhedral prisms showing zoning and polysynthetic twinning. It is highly weathered and altered to clay and sericite. Biotite forms less than 3% and is highly weathered and altered to iron oxides. Iron oxides occur as veins due to a solution rich in Fe.
42,43, 44, 45,46, 47	Granite, fine grain size, composed of feldspar and	Micrographic texture is evident. It consists of fine-grained quartz and orthoclase as the major minerals associated with each other. Plagioclase occurs as a minor mineral.

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48	quartz and secondary oxide minerals	Orthoclase and plagioclase are altered to kaolin and sericite. Biotite occurs in a low percentage, partially altered to chlorite. Iron oxides and calcite occur as secondary minerals filling the fractures and veins. The fractures show a dendritic texture. Phenocrysts of fractured quartz are present.
49	Granite, coarse grain size, feldspar, quartz and Biotite constitute the main mineral compositions.	The major textures are intergranular, consertal and poikilitic. It consists of about 30% quartz with highly fractured anhedral crystals. Feldspar occurs as both perthite and plagioclase. Plagioclase occurs as euhedral to subhedral prisms showing polysynthetic twinning It has been highly weathered and altered to calcite, clay (kaolin) with sericite as the rim. Perthite occurs as coarse-grained and is perthitic in texture with Carlsbad twinning. Mica sheets (biotite and muscovite) form about 5% and are highly weathered and altered to chlorite and iron oxide like masses. Calcite and iron oxides occur as secondary minerals filling fractures and veins. Opaque minerals occur as accumulated aggregates or masses while zircon occurs as an inclusion in the mica sheet.

4.2. Rock Geochemistry

The earlier regional geochemical survey of the rocks of the Upper Proterozoic (Aqaba and Araba complexes) in southwest Jordan had been conducted for the regional geochemical survey project **[15]**. The average concentrations (ppm) of the trace elements in the Aqaba and Araba complexes, that comprise the igneous and metamorphic suites, mostly of the late Proterozoic age were reported by **[15]**, as 10 mg/ton for Au, 15 ppm for As, 20 ppm for Cu, 15ppm for Pb, 7 ppm for Sn, 5 ppm for Mo, 9 ppm for Bi, 6 ppm for W, 5 ppm for Zn and 5 ppm for Li. According to **[16]**, the epithermal gold mineralization investigated in the Wadi Abu Khushayba within the calc-alkaline granitic rocks includes the late Proterozoic rocks within the Araba complex. The area under study includes the Aqaba complex and outcropping of the late Proterozoic calc alkaline granitoids.

The trace background values of the study area were taken as the mean and median values **[17],** as shown in **Table 1**. In fact, **[18]** suggested that the background could be used as the median**.** The separation between the background and anomalous values were defined using the classical statistical treatment with the threshold calculation from the mean and median plus two standard deviations (SD) **[19]**. The results from the data for the area of study were treated with statistically cumulative frequency plots. The statistical calculations for the area were more or less similar reflecting the search for a similar target lithology. The statistical treatment of the rock data resulted in the adoption of two threshold values (Threshold 1 = mean + 2 SD) and (Threshold 2 = median + 2 SD) respectively, and the background values were equal to the mean value. The data below the value of the detection limits were assumed as the minimum value of the analyzed element and the statistical parameters were then computed on this assumption and the maps of geochemical anomalies, **Fig. 3**. Thresholds 1 and 2 for Au equal 44 & 38.6, As 26.98 & 25.28, Cu 97.03 & 79.4, Pb 73.23 & 75.6, Sn 82.86 & 68.66, Mo 48.8 & 42, Bi 8.9 & 7.8, W 34.1 & 30.4, Zn 153.08 & 138.28 and Li 184.4 & 159.84, respectively (**Table 1)**.

The Pearson's correlation coefficients from among the concentrations of Au, As, Cu, Pb, Sn, Mo, Bi, W, Zn and Li found in the study of the rock samples are presented in **Table 2**. Low positive linear correlations among the concentrations of Au, Zn, As, Sn, Cu, Pb, Sn, Mo, Li and Bi were clearly observed: Au with Zn (r = 0.06), As with Sn (r = 0.16), Cu with Sn (r = 0.1), Cu with Zn (r = 0.03), Pb with Zn (r = 0.34), Sn with Zn, Li, Bi and W (r = 0. 27, 0.2, 0.17 and 0.032, respectively), Mo with Zn (r = 0.01) Zn with Li and Bi (r = 0.4 and 0.1). Strong, positive correlation of Au with As , Cu and W (r = 0.82, 0.7 and 1.0), As with Mo (r = 0.83), Cu with Pb (r = 0.83), Sn with Mo (r = 0.73), Mo with W (r = 0.97), Zn with W (r = 0.71), Li with Bi (r = 0.7), these correlations revealed that the hydrothermal alterations affect the association of the metals in the area and some metals, such as As and Bi, are good path-finders for Au **[20].** This may indicate that Au is found in association with sulfide minerals rather than quartz veins. The major correlation for the Cu, Pb, Zn, Sn, Mo and W components indicate that their association was with

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Title: Study of the metadynamic recrystallizaton behavior of a vanadium–nitrogen microalloyed steel

Name: Zhao Baochun*, Zhao Tan[1], Li Guiyan[1], Lu Qiang[2]

Affiliation: [1]Technology Center of AnGang Steel Company Ltd., Anshan, Liaoning, China 114001

Abstract: The metadynamic recrystallizaton behavior of a V–N microalloyed steel was studied by performing a two-pass isothermal compression test at 900℃–1050℃ at a strain rate of $0.1s^{-1}$ to $7s^{-1}$ with the inter-pass time of 0.2–2 s on a Gleeble-3800 thermo-mechanical simulator. The effects of the processing parameters on the metadynamic recrystallizaton behavior of the tested

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steel were analyzed, and the kinetic models were constructed. Our results showed that the metadynamic recrystallizaton of the tested steel can easily occur due to low activation energy. Higher deformation temperature, strain rate, or longer time interval contributes to an increase in the metadynamic recrystallized volume fraction. Finally, the kinetic models were confirmed by comparing the experimental and the predicted results.

Keywords: V–N microalloyed steel; Metadynamic recrystallization; Two-pass isothermal compression; Kinetics model

1. Introduction

In metal-forming processes, the hot rolling and forging processes often consist of several successive deformation passes for the creation of useful product shapes. Meanwhile, the process parameters for each pass are of great importance to the microstructure and mechanical properties of the final products[1-3]. During the hot deformation processes, dynamic recrystallization (DRX) occurs on condition that the stress or strain reaches a critical value and that the microstructure evolution can be phenomenologically described during the recrystallization process as nucleation and growth of new grains. In addition, metadynamic recrystallization (MDRX) is the growth of dynamically formed nuclei after cessation of hot deformation. In contrast to the case of MDRX, static recrystallization (SRX) also occurs during the cessation of hot deformation, while the stress or strain is below the critical value for the onset of DRX. Each of these mechanisms can alter the size or distribution of grains in materials and affect the transformation product characteristics on cooling, which plays the main role in the mechanical properties of the final products.

Several previous studies[4-8] have focused on the construction of the mathematic models for DRX, SRX, and MDRX to study austenite grain evolution, which permits the control or prediction of the final microstructure. However, the studies on MDRX for vanadium–nitrogen (V–N) microalloyed steel are limited. It is known that nitrogen is a cost-effective micro-element that plays an important role in the steel structures with vanadium addition[9]. The advantages of V–N microalloying technology to produce high-strength steel has been proved elsewhere[10,11]. Furthermore, vanadium carbonitrides can precipitate under certain deformation conditions, and these precipitated particles have a pinning effect at the austenite grain boundary. As a result, the austenite grain growth may be hindered. Since nitrogen can promote the precipitation process, addition of nitrogen to vanadium-microalloyed steels may result in changes of the DRX kinetics and MDRX kinetics of steel. Therefore, the understanding of the MDRX behavior of V–N-microalloyed steel to control coarse grains is of great importance.

In the present study, two-pass isothermal compression tests were performed on a Gleeble-3800 thermo-mechanical simulator to study the MDRX behavior of a V–N -microalloyed steel. The metadynamic-softening fraction of the tested steel was calculated by using an offset-stress method. With the assistance of metadynamic-softening fraction, the effects of temperature, strain rate, and time interval on the MDRX behavior of the tested steel were analyzed. Based on the experimental data, the MDRX kinetic models of the tested steel were established by the regression method. Finally, the predicted and experimental results were compared and contrasted.

2. Material and experiments

The chemical composition of the vanadium-microalloyed steel is C 0.17, Mn 1.5, Si 0.37, V 0.1, Ti 0.02, N 0.0120, and balance iron (wt%).

The tested steel was received from the continuous casting slab. Steel specimens of 12-mm

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height and 8-mm diameter were prepared. In order to reduce the occurrence of non-homogeneous compression, special anvils were employed. Both the ends of the specimen were covered with tantalum foils to prevent adhesion between specimen and anvils.

The specimens were austenitized at 1150°C for 5 min and cooled at the rate of 5℃/s to the deformation temperature and held there for 30 s before compression. Two-pass isothermal compression tests were conducted at the temperature range of 900–1050℃ at an interval of 50℃ and at the strain rates of 0.1, 1, 3, and 7 s^{-1}. The time intervals between the first and second pass are 0.2, 0.5, 1, and 2 s, respectively.

3. Results and Discussion

3.1 Stress–strain curves

Fig. 1 presents the typical stress–strain curves from the two-pass isothermal compression test. In the intervals of hot deformation, the changes in the microstructure mainly results from the occurrence of MDRX or SRX. When the strain imposed on the first pass is larger than the critical strain for the onset of DRX, metadynamic softening occurs during the intervals. In Fig. 1a and 1d, the curves of the tested steel in the first pass exhibited typical peaks at higher deformation temperature or lower strain rate, which suggests that the strain was larger than the critical strain for the onset of DRX. Since Poliak and Jonas[12] proposed the critical kinetic condition based on the principles of irreversible thermodynamics, the work-hardening rate θ, and stress σ curves have often been used to determine the critical stress corresponding to the critical strain. This method was used in the present study to prove that DRX can occur in the first pass, and it was found that DRX can occur at the deformation temperature of 900℃ and at the strain rate of 7 s^{-1}. Therefore, MDRX occurs under all experimental conditions. Fig. 1a presents the stress–strain curves of the tested steel at the strain rate of 0.1 s^{-1} and at the time interval of 0.2 s. Notably, stress in the second pass exhibits a platform, and it is hard to observe work hardening, indicating some amount of metadynamic softening. It can be explained that the softening induced by MDRX is not sufficient and that the dislocation density in the steel remains higher than the critical dislocation density for DRX, which is why the work hardening in the second pass can be annihilated by dynamic softening. Therefore, the stress tends to be constant, which leads to the formation of a platform in the curve. Furthermore, the stress is sensitive to temperature or the strain rate (Fig.1a, d). The effect of temperature or strain rate on MDRX has been discussed later. In Fig. 1b, it can be found that an increase in the time interval results in a decrease in the yield stress in the second pass, as a result, more work hardening in the second pass is recognizable. Compared with the curves in Fig. 1b, the curves in Fig. 1c exhibited more work hardening, especially at a short time interval of 0.2 s.

3.2 Calculation of metadyanamic-softening fraction

Presently, two methods are available to calculate the metadyanamic softening fraction: i) microstructure observation in which a sample is quenched at different intervals after single pass compression and the metadynamic softening fraction is determined by analyzing the quenched microstructure. ii) offset-stress method based on the relationship between stress change and microstructure evolution during hot deformation. Presently, the latter is widely used to calculate metadynamic softening fraction. Compared with the 0.002 offset-stress method, 0.02 offset–stress method is comparatively insensitive to recovery. Therefore, the metadynamic-softening fraction is calculated by using the 0.02 offset–stress method as follows:

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$$X = \frac{\sigma_m - \sigma_2}{\sigma_m - \sigma_1} \quad (1)$$

Where, σ_m is the stress at the first interruption and σ_1 and σ_2 are the offset stresses (2%) at the first pass and the second pass, respectively.

3.3 Effects of the processing parameters on the MDRX volume fraction

Fig.2 presents the relationship between the processing parameters and the MDRX volume fraction. Notably, the effects of deformation temperature, strain rate, and time interval on the MDRX volume fraction are marked.

3.3.1 Effects of deformation temperature

With a constant strain rate and time interval, MDRX volume fractions increase with the increasing deformation temperature. Since recrystallization process is a thermally activated process, atomic vibrations can be enhanced with increasing temperature and the atomic-binding forces become weak, which promotes dislocation movement and then promotes recrystallization. As shown in Fig.2a, the MDRX volume fractions increase markedly with increasing temperature when the time interval is 0.2 s. With longer time interval, the effect of temperature decreases and the curve appears relatively flat; this phenomenon is induced by the rapid MDRX over longer time interval.

3.3.2 Effects of strain rate

The effect of strain rate on MDRX volume fractions is shown in Fig.2b. An increase in the strain rate results in an increase in the MDRX volume fractions. Furthermore, higher strain rate markedly increases the MDRX volume fractions at higher temperature. At the deformation temperature of 1050℃ and the strain rate of 0.1 s^{-1}, the MDRX volume fraction was 32%, while the value reached 83% at the time interval of 0.2 s. There are two main reasons for this: i) higher strain rate increases the effect of work hardening and simultaneously decreases the softening effect of dynamic recovery and DRX, which results in higher dislocation density or stored energy that contributes to increasing the driving force for MDRX. As a result, the MDRX volume fraction increases. Ii) an increase in the strain rate leads to a decrease in DRX volume fractions, while an increase in the strain rate leads to an increase in the number of dynamic recrystallized nuclei. In addition, increasing number of nuclei can accelerate the MDRX process.

3.3.3 Effects of time interval

Fig.2c presents the effect of time interval on MDRX volume fractions. With a constant deformation temperature and strain rate, MDRX volume fractions markedly increased with an increase in the time interval from 0.2 s to 1 s, while the increasing trend slows at the time interval above 1 s. At the deformation temperature of 1050℃ and the strain rate of 0.1 s^{-1}, the MDRX volume fractions corresponding to the time interval of 0.2, 0.5, 1, and 2 s are 29.4, 54.29, 72.2, and 81.1%, respectively. The stored energy in the grains can be released with an increasing time interval, which promotes dislocation movement that is favorable for grain growth. As a result, MDRX volume fraction increases with increasing time interval. With the release of stored energy, the dislocation movement slows near the end of full MDRX, which is why a small increase in the MDRX volume fractions can be recognized.

3.4 Modeling the kinetics of MDRX

It is known that MDRX and SRX are two different mechanisms, and the effects of process

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parameters on the two mechanisms are also different[13]. However, both these mechanisms can be described by an Avrami equation of the following form[14]:

$$X_{mrex} = 1 - \exp[-0.693(\frac{t}{t_{0.5}})^n] \qquad (2)$$

Where, X_{mrex} is the MDRX volume fraction, n is the material dependent constant, and $t_{0.5}$ is the time for 50% recrystallization. Generally, $t_{0.5}$ is widely expressed as follows:

$$t_{0.5} = A\varepsilon^p \exp(\frac{Q_{mrex}}{RT}) \qquad (3)$$

Where, $\dot{\varepsilon}$ is the strain rate, Q_{mrex} is the apparent activation energy of MDRX (kJ/mol), R is the gas constant (J/mol K), T is the deformation temperature (K), A and p are material-dependent constants.

Taking the natural logarithm of both sides of formula (2) twice gives the following:

$$\ln(\ln(\frac{1}{1-X_{mrex}})) = \ln 0.693 + n\ln t - n\ln t_{0.5} \qquad (4)$$

For a given material, n is a constant. A linear relation between $\ln(\ln(\frac{1}{1-X_{mrex}}))$ and $\ln t$ is recognizable and the parameter n is the slope of the line. The values of parameter n corresponding to different deformation conditions can be obtained by the linear regression method. Fig.3 presents the lines corresponding to different deformation conditions. It is easy to obtain the average value of parameter n as 0.603.

Taking the natural logarithm of both the sides of formula (3) gives the following:

$$\ln t_{0.5} = \ln A + p\ln\dot{\varepsilon} + \frac{Q_{mrex}}{RT} \qquad (5)$$

Formula (5) presents the relation between $\ln t_{0.5}$ and $\ln\varepsilon$ or 1/T is linear, as shown in Fig.4 or Fig.5. With a specific strain rate, Q_{mrex} can be obtained by the linear regression method. Therefore, the apparent activation energy Q_{mrex} is obtained as 147.158kJmol^{-1}. Similarly, the value of parameter p also can be obtained as -0.366. With the assistance of Q_{mrex} and p, the value of parameter A can be obtained as 2.358×10^{-7}. Therefore, the kinetics models of MDRX for the V–N microalloyed steel can be obtained as follows:

$$X_{mrex} = 1 - \exp[-0.693(\frac{t}{t_{0.5}})^{0.603}] \qquad (6)$$

$$t_{0.5} = 2.358\times10^{-7}\dot{\varepsilon}^{-0.366}\exp(\frac{147158}{RT}) \qquad (7)$$

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